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NATURAL PHILOSOPHY.

FIFTH TREATISE.

OPTICS.

NOTICE.

THE following treatise is intended to present a systematic exposition of the properties of Light and the laws of Vision, compatible with the scope and design of an elementary text-book. Though avowedly rudimentary, a glance at the table of contents will show that no important feature of the science has been omitted, while in example and illustration the respective sections will be found more than usually profuse. The utmost care has been taken to render the treatment at once precise and simple—the aim being to inculcate principles, not to amuse the student with mere descriptions of natural phenomena or accounts of optical instruments and contrivances, however ingenious.

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OPTICS

OR THE SCIENCE OF LIGHT AND VISION.

1. OPTICS is the science that treats of the properties of Light, and the laws of Vision. It explains the motions of the rays that issue from luminous centres, their bendings and reflections from the surfaces of bodies, their varied actions in producing colour, and the instruments which have been constructed for concentrating or dispersing them. It treats of the human eye, and of the mechanism whereby it can bring pictures of the outer world within the reach of the mind's perception; and describes the artificial methods of enlarging the sphere of ordinary vision, so as to extend it to remote distances on the one hand, and to indescribably minute objects on the other.

2. The least sensible portion of light is called a *ray;* a *beam* of light is a collection or bundle of parallel rays; a *pencil* of light is a parcel of rays proceeding from or towards some point. The form of a pencil is usually considered to be conical, and its geometrical axis—that is, the line joining its apex and the centre of its base—is termed the *axis* of the pencil. When the pencil proceeds from a point, and is therefore continually widening, it is said to be *divergent;* and when the rays of a pencil verge towards a point, whether they are allowed to reach it or not, it is called a *convergent* pencil.

3. The point from which a pencil diverges is called a *radiant* point. Thus if the sunlight is made to pass through a small circular aperture in a card or thin piece of metal, it will form a divergent pencil, of which the aperture is the radiant point: a very minute flame, the reflecting portion of a globule of mercury, or of a bead, are also radiant points.

The point towards which the rays of a convergent pencil tend, or in which they meet, is called a *focus* or *focal point.* Thus when the sun's light passes through a common eye-glass, it unites in a point which is strongly illuminated; being in fact a very small image of the sun: the rays, which were parallel before reaching the lens, become convergent after passing through it, and are concentrated in a luminous point, which is the focus. The focus of convergent rays is *real* when they actually meet; and it is said to be *virtual* or *imaginary* when they are prevented from meeting.

NATURE OF LIGHT.

4. There are two different views maintained regarding the nature of light. According to one, light is considered to be a material substance, consisting of particles that are emitted or showered in all directions from a luminous body, and so fine as to pass through the inconceivably minute pores of transparent bodies; and by striking—that is, impinging—on the retina of the eye, excite the sensation of vision. In the other view, vibrations are conceived to be excited by the luminous body in a highly elastic and subtile fluid called an *ether*, which is conceived to pervade all space, and even the pores of all bodies; these vibrations are propagated in all directions with immense velocity, and by striking on the eye produce the sensation of light, in the same manner as the feeling of sound is excited in the ear by vibrations of the air proceeding from some sonorous body. The former of these views is called the *theory of emission*, or the *material theory of light;* and the latter the *undulatory theory.*

5. The theory of emission was devised by Newton, and for a long time it was thought to explain the facts better than any other. It is not necessary to suppose that the particles succeed each other closely, so as to crowd the whole of space with a luminous stream. It is found that a single impression of light will remain on the eye for the eighth of a second; and therefore, if eight particles fell upon it every second, there would be a permanent impression produced. But in the eighth of a second a ray passes through 25,000 miles, so that if one particle followed another at this distance, constant light would be maintained; and the shower would be so thin and scattered, that there would be room enough for all the innumerable crossings of luminous rays. At the present day, however, there are many phenomena that cannot be explained by this theory, and that are found more consistent with the undulatory hypothesis.

RECTILINEAL PROPAGATION OF LIGHT.

6. The optical phenomena arising from the motion or propagation of light in straight lines, are comparatively few and simple:—That the direction in which light moves is rectilineal, is easily proved by experiment. For instance, a luminous body can be seen through a straight tube of very small bore, when accurately directed to it; but it would be invisible through the same tube if it were bent. So if small apertures are made in a row of cards, an object will be seen through them only when they are arranged in the same straight line with the light.

ABSORPTION OF LIGHT.

7. When a medium is imperfectly transparent, or when a portion of the light gradually disappears in passing through it, the light is said to be *absorbed* by the medium; and its intensity continually diminishes, so that after passing through a certain thickness or depth it becomes insensible. Were light composed of material particles, this absorption would be the literal explanation of the occurrence; but if it consists merely of vibrations, the fact must be explained by supposing that the particles of the medium weaken the vibrations, till at last they become so feeble as to be incapable of exciting the sensation of light. Thus when light is transmitted through a plate of glass, a portion of it is absorbed; and if it passes through a certain number of plates, it will become so faint as to be insensible; or objects would be invisible through such a succession of plates. In consequence of the absorption of light, even by the purest air, the celestial bodies themselves would be invisible if the atmosphere were of very great extent. On the same principle a glass cylinder might be so long as to be impervious to light in the direction of its length, although the two ends were finely polished.

8. That portion of the light proceeding from a heavenly body which is absorbed by the atmosphere, is great when the body has a small height above the horison; but at very high altitudes it is small. The cause of this difference is evident. Light proceeding from a celestial body near the horison, passes through a much greater extent of atmosphere, especially the denser part of it, than light from an object at a considerable elevation. The quantity of light thus absorbed will be easily known from the subjoined table, which gives the number of rays out of 10,000 that reach the eye for

different altitudes. The first, third, and fifth columns contain the apparent heights in degrees, and the second, fourth, and sixth the number of rays that penetrate through the air:—

Degrees.	No. of Rays.	Degrees.	No. of Rays.	Degrees	No. of Rays.
0	6	8	2423	30	6613
1	7	9	2797	35	6963
2	192	10	3149	40	7237
3	454	11	3472	50	7624
4	802	12	3773	60	7[illegible]6
5	1201	15	4535	70	8016
6	1616	20	5474	80	8098
7	2031	25	6136	90	8123

INTENSITY OF LIGHT.

9. Like all influences diffused from a common centre, the intensity of light is inversely as the square of the distance from the luminous body—that is, in the ratio of 1, 4, 9, 16, &c. Thus if a board, *a*, a foot square, be placed at the distance of one foot from a candle, it will be found to hide the light from another board, *b*, of two feet square, at the distance of two feet from the candle. Now a board of two feet square is just four times as large as one of one foot square, and therefore the light at double the distance being spread over four times the surface, has only one-fourth the intensity. By artificial means, rays of light can be made to move parallel to one another, and in that case their intensity will be the same at all distances, except in so far as it is diminished by absorption.

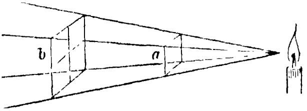

Fig. 1.

10. As the term *sine* of an angle will have to be frequently used in Optics, especially when treating of refraction, we shall here give an explanation of it. In the annexed diagram, the arc from L to P is the fourth part of a circle, and is divided into 90 equal parts, called degrees. The arc from L to 60 is an arc of 60 degrees; degrees being represented by a small ˚ over the number, this arc is simply expressed as an arc of 60°. The inclination of the line H 60 and H L—that is, the angle at the point

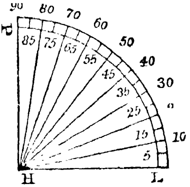

Fig. 2.

H subtended by the arc L60 is therefore 60°; so the angle at H subtended by the arc L40 is an angle or inclination of 40°. [See MECHANICS, p. 36.]

11. An angle is usually expressed by three letters; thus P H D (fig. 3) means the angle at H formed by the two lines P H, H D; the letter H at the angular point being in the middle between the other two. Now this angle is measured by the number of degrees in the circular arc P L, whose centre is H. The *sine* of this angle, when P H the radius of the arc is considered to be the unit of measure of length, or equal to 1, is the line P D drawn from P perpendicularly to H L; and it is evident that the smaller the angle at H is, the smaller is the sine P D also; the angle and the sine, however, are not exactly proportional.

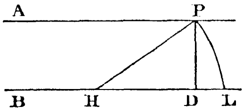

Fig. 3.

12. Now if A P B H represent a portion of a pencil of parallel rays intercepted by a plane P H, this plane will intercept exactly the same number of rays as a shorter plane P D would do; hence the quantity of light received by the plane P H is exactly proportional to P D, the sine of P H's inclination to the direction H L of the light.

13. For example, the distance of Mercury from the sun being little more than one-third of the earth's distance, the intensity of the sun's light and heat on the former will be to that on the earth inversely as the square of $\frac{1}{3}$ to the square of 1, or as 9 to 1; that is, the heat and light at Mercury are 9 times as powerful as on the earth. Venus is about two-thirds of the earth's distance from the sun; hence the intensities of the sun's light on the two are inversely as 2 square to 3 square, or directly as 9 to 4; so that the light and heat at Venus are more than double the force of these on the earth.

14. Since light falling obliquely on a surface is fainter than when it falls perpendicularly, the sun's light in the tropical regions, where he is nearly vertical, is more intense than in higher latitudes, where his rays strike the earth's surface more obliquely. For the same reason, the light and heat received by a square foot of the earth in winter, at any given place, are less than in summer, when the sun attains a greater height; and this, together with the shortness of the day, is the cause of winter being colder than summer.

Photometers.

15. Various instruments have been invented for measuring the intensity of light; these are called *photometers*, from the

Greek words *phōs, light*, and *metron, a measure.* Some of them are constructed on the principle that light and heat are proportionally united in the luminous rays, and may be called *thermometric* photometers: these are adapted to indicate only which of two lights of the same kind has the greater intensity; as of the sun under different circumstances, of two candles of the same kind, or two gas jets of the same quality of gas; for it cannot be assumed that light and heat are united in one proportion in lights from different sources. There are two thermometric photometers, one by Leslie, and another by Ritchie. The former is a glass tube with bulbs on both ends, and bent into the form of the letter U, the bulbs being uppermost; the greater part of the stem is filled with coloured sulphuric acid; the action of light, or rather of heat, on one of the bulbs, expands the air in it, and depresses the column of acid, and from the extent of the depression the strength of the light is inferred; but it does not give any measure of relative intensity. In Ritchie's instrument, instead of bulbs there are short tubes of turned-iron plate close at one end, and having their other ends covered by disks of glass, and rendered perfectly air-tight; these tubes are closely fitted to the ends of the bent glass tube, and the two lights to be compared are placed so that each acts on the air in one of the cylinders, by passing through the glass; and when the air, by its expansion in one stem, depresses the fluid, the light acting on that side is removed to a greater distance, till the two actions exactly counterbalance each other, or till the fluid is at the same height as before the operation. Then the *intensities* of the two lights will be inversely as the squares of their distances from the instrument. The two cylinders are placed with their axes in the same straight lines, and in the middle of each is a piece of black bibulous paper placed parallel to the ends, to absorb the light and heat.

16. Count Rumford measured the intensity of lights by the method of shadows. The two shadows of an opaque object, as a bit of card, formed on a white screen by two lights, are brought near to each other by a proper position of the lights; and it is evident that each shadow will be illuminated by the rays of the other light. The light that shines on the less dark shadow is removed till the darkness of both shadows is equal; the illuminating powers of the two lights on the screen will then be equal, and hence their real intensities will be inversely as the squares of their distances from the screen.

17. Thus if S C (fig. 4) is a screen, and O B an opaque body, both being perpendicular to the plane of the paper, and P and Q two lights; the shadow E C caused by the object O B

intercepting the light of P, is evidently illuminated by Q, and P illuminates the other shadow R S: now when the two shadows are equally dark, it is evident that P and Q shine with equal brightness on both, and their intensities will therefore be inversely as the squares of their distances, P R and Q C; that is, the intensity of P is to that of Q as the square of Q C to that of P R.

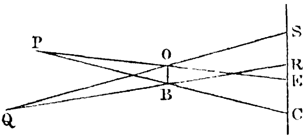

Fig. 4.

18. The best photometer for artificial light is one invented also by Dr Ritchie. It consists of a rectangular box, of which A R C T is a vertical section in the direction of its length; in it is placed two plane mirrors Z X, Z Y, inclined to the vertical line m Z at an angle of 45°; on the upper side of the box is an opening $p\,e$, covered with oiled paper, or any translucent plate or disk; and a narrow slip of black card is pasted along the line Z where the edges of the mirrors join. The two lights to be compared are now placed at P and Q, and their rays being reflected by the mirrors to the oiled paper, it can be observed by looking down on the paper if the illuminations are equal. If they are unequal, one of the lights is removed farther off till they are made equal; the intensities of the lights will then be inversely as the squares of their distances from the central line m Z. If the distances of two candles, when the illuminations are equal, are 4 and 6 feet, their intensities are as 16 and 36, or as 4 and 9, the nearer light being of course the less intense.

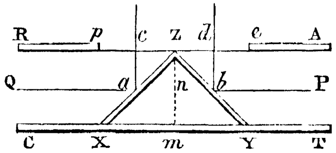

Fig. 5.

19. It has been proved experimentally that the light of the sun is 300,000 times stronger than the light of the moon when full and at its mean distance from the earth; and that the light of the sun becomes insensible only when it is diminished to the 1,000,000,000,000th part of itself.

SHADOWS OF OPAQUE OBJECTS.

20. When an opaque object is placed in a pencil of light, it stops or intercepts a portion of the rays, and the space behind the object is consequently in darkness; this dark space is

called the *shadow* of the object. Thus if A B (fig. 6) represent the sun, C D the earth, and M the moon, the dark conical space C D V is the shadow of the earth.

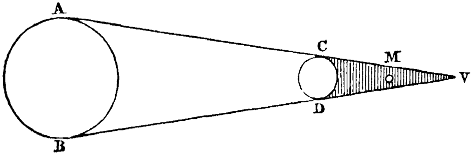

Fig. 6.

21. When the luminous object is very small, so that it may be considered as a mere point, the shadow will not taper to a point as in the figure, but will continually increase in breadth. Thus if V were the luminous object, and C D the obstacle, C D B A would be a portion of the shadow.

22. When the luminous body is distant, the shadow of an illuminated object on a screen near it is similar to the object; but with the screen at a considerable distance, the shadow is similar to the luminous body itself. The shadow of an irregular obstacle placed in the sun's light has the form of the obstacle when the screen is near; but the shadow is circular like the sun when the screen is at a great distance.

23. These observations regarding shadows are applicable to the illuminated space formed on a screen by making the sun's light pass through an aperture. When the screen is near the aperture, its illuminated portion is similar to the opening; but when the screen is sufficiently distant, it is similar to the luminous body. The interstices between the leaves of trees are so many small irregular apertures; hence the cause of the numerous small bright circles seen in a sunny day in the shadow of a tree, or still more distinctly in that of a grove.

24. Besides the real shadow of an object, which would be perfectly black were there no light reflected to it from other bodies, there is a partial shadow surrounding the real one, called the *penumbra*, which receives light from only a portion of the luminous body, and becomes gradually lighter from the border of the real shadow to that of the fully-illuminated space; it thus contains between its limits every possible degree of light.

IMAGES FORMED BY DIRECT LIGHT.

25. When light from a luminous surface passes through a minute aperture, so small as to be considered as a mere point,

the rays will form an *image* of the surface exactly similar to it, though *inverted*. Thus the pencil O A B from the luminous body A B will, after passing through the small aperture O in the opaque surface M N, form on a screen beyond it the illuminated figure P Q, which will evidently be inverted, because a ray A O P from the lower part of the surface A B, will form at P an image of the point A; and in like manner a ray B O Q emanating from B will form an image of it at Q.

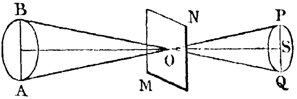

Fig. 7.

26. Let now B R be an elongated object, sufficiently illuminated by the sun or other light to emit from every point of it, and in all directions, sensible pencils of light; let C D be a window-shutter, and E F a white screen of cloth, or pasteboard, or simply the white wall in a dark room; a person in the room will then see an inverted image *b r* of the arrow; for any point B sends off a pencil, of which B is the apex, and when A is circular, the base a minute circle at *b*, called the image of B. Similarly the images of the points G and R will be at *g* and *r*, and the whole image *br* of the arrow will thus be inverted. If the object be of different colours in different parts, the image *b r* will be similarly coloured.

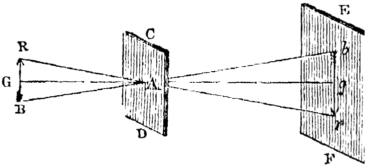

Fig. 8.

VELOCITY OF LIGHT.

27. The velocity with which light is propagated is about 200,000 miles a second, so that it could pass nearly ten times round the earth, or once between the earth and moon, in one second of time. Hence the flash of a gun at a considerable distance is observed at the same instant that it is fired off, though a sensible time elapses before the report is heard. The progressive motion of light was discovered from the fact, that the eclipses of Jupiter's satellites happen so much later as Jupiter is farther from the earth.

CATOPTRICS

OR THE REFLEXION OF LIGHT.

28. When light falls on the surface of a body, it is said to be *incident* light; and the portion that is thrown back from the surface is said to be *reflected.* In every case of light falling on a body, some portion of it is reflected. There are two modes of reflexion: in the one, the light is thrown off from the surface in all directions, and renders the body visible; in the other, it is thrown back in only one direction, which is related to the direction of the incident light. The latter mode is the most intense, and constitutes *mirror* reflexion: it is the kind exclusively treated of in Catoptrics. The quantity of the reflected compared with the incident light depends on the nature of the surface that reflects it.

29. The atmosphere, although a very light and almost colourless elastic fluid, reflects so much of the sun's light in all directions upon surfaces exposed to it, as to render them visible. Did the air not possess this property, no object would be seen unless it received the direct rays of the sun or some artificial light; the sky would be perfectly black, and the sun, by the contrast, would appear to be of more intense splendour, and the shadows of all bodies would be spaces of total darkness. On account of the rarity of the air in the higher regions, as on the tops of lofty mountains, it is incapable of reflecting much light; so that to a spectator at a great height the heavens appear of an intensely dark colour, and the stars shine with unusual brightness.

30. A polished surface, capable of reflecting a large portion of the light incident on it, is called a *speculum*, or *mirror*. The former term is, however, usually restricted to metallic surfaces, and the latter to silvered glass—that is, glass coated with tinfoil previously amalgamated with a small quantity of mercury. But the term mirror, besides this specific meaning, has in optics a general application to every surface used for reflecting light. Mirrors are either *plane* or *curved*, according as their surfaces are plane or curved; and as curved surfaces are either concave or convex, so curved mirrors are termed *concave* or *convex*, according as they are hollow or bulged.

Since in the case of a glass mirror the light reflected from its nearest surface is almost insensible when compared with the reflexion at the second surface from the amalgamated tinfoil, such mirrors also are, properly speaking, metallic reflectors, the glass being used to give the tinfoil a very smooth and fine surface, as if it were polished.

REFLEXION BY PLANE MIRRORS.

31. If A B be a plane mirror lying in a horizontal position, with its reflecting face uppermost, a ray of light falling on it in the direction *e d* will be reflected in the line *d b;* so that the angle *ed*B shall be equal to *b d* A; or if *c d* be a line perpendicular to the surface A B, the angle *c d e* shall be equal to *c d b.*

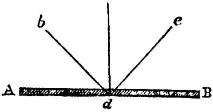

Fig. 9.

32. A ray of light falling on a reflecting surface is called an *incident ray;* a ray reflected at a surface, a *reflected ray;* and the point on the surface which the incident ray strikes, the *point of incidence.* Thus *ed* is the incident ray, *db* the reflected ray, and *d* the point of incidence. A perpendicular drawn to a reflecting surface at the point of incidence is called a *normal;* the angle contained by the incident ray and the normal is called the *angle of incidence;* and that contained by the reflected ray and the normal, the *angle of reflexion.* Thus *cd* is the normal, *cde* the angle of incidence, and *cdb* the angle of reflexion. The angles made by the incident and reflected rays with the reflecting surface may be termed the angles of *co-incidence* and *co-reflexion,* as the angles B*de* and A*db;* and since these latter angles may sometimes be more conveniently referred to than the angles of incidence and reflexion, it is proper they should have a specific name. When the axis of a pencil is perpendicular to the reflecting surface, it is said to be a *direct pencil;* in other cases, an *oblique pencil.*

33. The principle stated in article 31 may now be enunciated thus:—The angle of reflexion is always equal to the angle of incidence, and the angle of co-reflexion is always equal to the angle of co-incidence. When an incident ray, or the angle and the point of incidence, are given, and also the reflecting surface, the reflected ray can easily be found by means of the preceding principle. Thus let the position of the reflecting surface AB be given, and let *ed* be the incident ray; then draw the normal *cd,* which is perpendicular to the surface;

next draw the line *db*, so that the angle *cdb* shall be equal to *edc*; and *db* is the reflected ray.

34. If there were another incident ray parallel to *ed*, the reflected ray would be parallel to *db*; and hence, when the incident pencil consists of parallel rays, the reflected pencil is also composed of parallel rays. When a ray is incident in the direction of a reflected ray, the reflected ray corresponding to the former coincides with the incident ray corresponding to the latter; that is, if a ray were incident in the direction of *bd*, the reflected ray would be in the direction *de*. And, in general, if a ray proceeding from some radiant point undergoes any number of reflexions, and reaches a particular point, a ray proceeding from the latter point could pursue exactly the same path in an inverted direction, and arrive at the original radiant point. The radiant point of incident rays, and the focus of reflected rays, are together called *conjugate* foci.

35. Thus if M be the focus of a divergent pencil, the extreme rays of which are M D, M F incident upon the plane mirror R R′, then the reflected rays will be D *i*, F *k*, which, if traced back, would converge towards the imaginary focus *m*; so that M and *m* are the conjugate foci, *m* being the focus of the reflected pencil. So if *i* D, *k* F are the extreme rays of an incident converging pencil, whose imaginary or virtual focus is *m*, they will be reflected in the directions D M, F M to the real focus M.

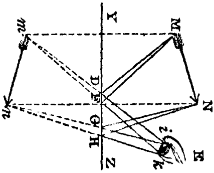

Fig. 10.

36. In both these cases the triangles M D R, *m* D R are equal in every respect, and the side *m* R is equal to M R; and hence the following theorem:—When a pencil of rays is reflected at the surface of a plane mirror, the conjugate foci are on opposite sides of the surface, and equidistant from it; and the line joining them is perpendicular to the surface, or, in other words, the conjugate foci are symmetrically situated in reference to the mirror.

Images formed by Reflexion with Plane Mirrors.

37. Since rays proceeding from a point, and falling on a plane mirror, converge towards an imaginary focus on the other side, which is at the same distance from the mirror as the radiant point, or symmetrically situated in reference to the mirror, the rays proceeding from every point in any object, considered each as a radiant point, will, after reflexion

at the surface of a plane mirror, converge towards their respective conjugate foci behind the mirror, and will form a virtual image exactly similar and equal to the object, and similarly—that is, symmetrically—situated. If the object is straight and parallel to the mirror, so is its image; if straight and inclined, its image is also straight and equally inclined.

38. These facts will appear more distinctly by considering the diagram above (fig. 10), in which R R′ is the plane mirror, and M N the object—an arrow, for example—*mn* will be its image, equal to M N; every point of it being at the same distance behind the mirror as the corresponding point in M N is before the mirror; also the object and image are equally inclined to the plane of the mirror, and are symmetrically situated. The rays, for instance, diverging from M, considered as a radiant point, will converge after reflexion to the imaginary focus *m*, and those from N will converge to *n*. It is, however, to be observed that, to a person anywhere situated before the mirror, as at E, only a small pencil out of all the rays falling on the mirror from the divergent pencil proceeding from the point M, can be reflected to the eye; namely, the small conical pencil limited by the rays M D, M F, of which the pupil of the eye is the base, and this pencil produces an image the same as if it proceeded from *m* as a radiant point; and therefore to the observer there appears a material point, as if situated at *m*, exactly similar to the point M. So a point appears as if situated at *n* exactly similar to the point N.

39. When the object is crooked or curved, it is evident that its image must be crooked or curved, and symmetrically situated in regard to the mirror. If a person were standing with the right side of his face towards M, the left towards N, and his face towards the mirror, the image of the right side would be at *m*, and of the left at *n;* there would therefore be an inversion of the face in reference to a horizontal direction, or right and left. There would, however, be no inversion in reference to a vertical direction, or up and down; the image of the head would be uppermost. It appears, then, that in looking at an image in a plane mirror, there is an inversion only in one direction; on this account such images are said to undergo a *semi-inversion*. To make this circumstance more evident, take a square card, and on one side of it mark the corners 1, 2, 3, 4, and hold it parallel to a plane mirror, with the marked face looking at the mirror; the numbers on the image of the face will be in an order the reverse of that on the card. If, for instance, the numbers on

the card beginning with 1 are read from left to right, then they will be read in the image from right to left.

40. Any straight object being held parallel to a plane mirror, its *entire* image will be seen by an eye situated anywhere in the line of the object, if the mirror is half the length of the object.

41. Let C D be the object, A B the plane of the mirror, and *C′ D′ the image; if an eye be situated at* E *in the line of* C D, *the image of* C *will appear at* C′; *since if* C M *is one of the rays of the small pencil proceeding from* C, *it is reflected to* E *in such a manner that* M E *is in the direction of the straight line joining* C′ and E. For a similar reason, the image of D at D′ will be seen by the eye E by means of a small pencil, of which R E is one of the reflected rays. The images of other points of the object are evidently seen by means of rays reflected from parts of the mirror lying between M and R; hence the whole length of mirror necessary to show the whole image of C D is merely M R, which is proved by a simple geometrical process to be half of C′ D′, or C D.

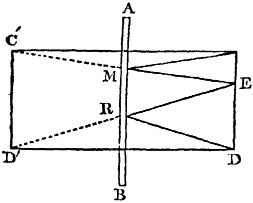

Fig. 11.

42. On this principle a person will see the whole length of his own image by means of a mirror of half his length, provided the top of the mirror M is held on the same level as a point half way between the crown of the head and eye, or the middle of C E.

43. When C D is a line, the eye might be situated either above C or below D, provided it be in the line of C D, and the same conclusions would follow; only the mirror M R would require to be placed higher or lower, according to the position of the eye.

Multiplication of Images by Reflexion.

44. If two plane mirrors be placed with their faces *parallel*, and turned towards each other, and an object be placed anywhere between them, there will be seen in both mirrors a series of images extending indefinitely, and becoming less distinct as they recede, till at last they cease to be visible. This multiplication of images arises from the repeated reflections of the rays of light proceeding from the object. The first image of the object in one of the mirrors formed in the ordinary way, is reflected by the other mirror, as if it were

itself an object; it thus causes to be formed in the second mirror an image as far distant behind the face of the latter as the first image lies from it in front: this last image, in the same manner, again causes a third image to be formed in the first mirror still further remote; and thus a series of images gradually receding is formed — the first, third, fifth .... images are formed in the first mirror, and the second, fourth, sixth .... are formed in the second mirror. A similar series of images is formed by the first image of the object in the other mirror.

45. On the principle of repeated reflexions, several entertaining catoptric instruments are constructed. One of these is a *catoptric cistula*, as it is termed, or box in the form of a regular hexagonal prism; that is, a box with six equal sides. It rests on one end, and the upper end is covered with a firmly-braced translucent membrane (such as parchment rendered permeable to light by being washed first in a clear lye, and then in warm water). The inner sides are lined with plane mirrors; a small portion of their silvering being taken off about the middle, and apertures opposite to the bare parts made in the sides of the box, so that the interior may be seen through them. If a number of small flowers of different kinds, or any other ornamental objects, are now placed in the box, they will form a pleasing group of images immensely multiplied, and diffused over an apparently vast space.

46. Another interesting catoptric instrument, of some utility in the art of design, is the *kaleidoscope*, invented by Sir David Brewster. In its simplest form it consists of two slips of mirror about 8 inches long, and 1½ broad, placed so that their long edges join at an angle of 60°. They are then fixed in this position, and placed in a tube covered at one end with an opaque plate, having an opening in the centre for looking through; the other end is fitted up with two circular disks of glass a little distance apart, so as to hold between them a few pieces of differently-coloured objects, as bits of variegated crystals, minute flowers, &c. In looking through the eye-hole of the tube, these small objects appear to be multiplied and regularly arranged in a polygonal form, the centre of the figure being the angular point where the glasses meet. When the inclination is 60°, each figure will consist of six similar portions, and will thus have a hexagonal form; if the angle be 45°, the figure will be octagonal in form; and so on.

47. Experiments in what is called *magical perspective* are performed by means of successive reflexions by combinations of plane mirrors placed at an inclination of 45° to the direc-

tion of the light. An instrument of this kind, which may be denominated the *magical telescope*, is thus constructed:

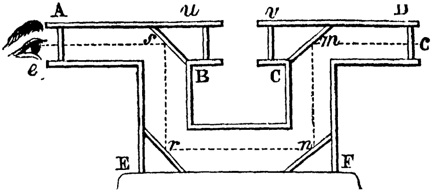

Fig. 12.

A B, C D are the perspective tubes in the direction of whose axis the observer looks; the supports B E, C F instead of being solid, are also tubular, and four small plane mirrors *m*, *n*, *r*, *s*, are placed with the faces of every two in succession turned towards each other, and inclined at 45° to the direction *mc* of the incident light; then it is evident that, since the angles of reflexion are equal to the angles of incidence, the course of the ray will be *cm*, *mn*, *nr*, *rs*, and it will at last be reflected in the direction *s e* to an eye at *e;* and the object will appear in the direction *ec*, as if the light proceeded straight through the tubes A B, C D. A thing may thus be seen, although an opaque screen, or the hand, be interposed between the ends B C of the tubes. The deception is more complete when the ends of the tubes A B, C D are closed with round disks of plane glass.

REFLEXION BY SPHERICAL MIRRORS.

48. Of curved mirrors only the particular kind called *spherical* are commonly used. Spherical mirrors are portions of spheres, or rather of spherical shells, and are either *concave* or *convex* according as the interior or the exterior surface is polished.

49. Let A V B (fig. 13) be a concave mirror; then if G I D be a plane touching the surface in I, the line C I perpendicular to this plane is the *normal* to the surface; that is, the normal to the surface is a perpendicular to the tangent or touching plane; and when the mirror is spherical, this normal is a *radius* of the spherical surface.

50. If R I be an incident ray, and I T the reflected ray, R I C and C I T are the angles of incidence and reflexion, which are equal as in the case of plane mirrors. Hence—

51. When the point of incidence and the direction of a ray

incident on a spherical mirror are known, the direction of the reflected ray will be found by making the angle of reflexion equal to the angle of incidence.

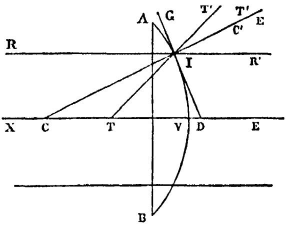

Fig. 13.

52. When the mirror is *convex*, the radius I C produced to C′ will give the normal to the convex surface; and if R′ I the direction of a ray incident at I be given, the direction I T′ of the reflected ray will be found exactly as in the case of the concave mirror, by making the angle C′ I T′ of reflexion equal to R′ I C, the angle of incidence.

53. The centre C of the spherical surface, of which the mirror is a portion, is called the *geometrical centre* of the mirror, or its *centre of curvature.*

54. The boundary or edge of the mirror is commonly a circle, of which A B is the diameter. The point V, which is the central point of the surface, and is equidistant from the edge, is called the *optical centre* or *vertex* of the mirror.

55. The line that passes through the geometrical and optical centres of the mirror is called the *axis* of the mirror.

56. The terms *direct* and *oblique* pencil have the same meaning in the case of spherical reflectors as in plane mirrors. A direct ray incident on a concave or convex mirror must pass through the centre of curvature, or the centre of the completed sphere.

57. Thus if C I were an incident ray, or the axis of an incident pencil, it would be direct; and R I would be the axis of an oblique pencil.

58. The plane of incidence or reflexion is the plane passing through the axis of the incident pencil and the normal or radius at the point of incidence. Thus if R I were the axis of the incident pencil, I the point of incidence, and C I the radius, R I C would be the plane of incidence. Hence since every normal must pass through the centre of curvature, every plane of incidence must pass through the same point.

59. The axis of a pencil has already been defined. The *principal ray* of an incident pencil is either a real or an imaginary ray passing through the centre of curvature.

60. A *principal section* of a mirror is the arc on it which is the intersection of a plane passing through its axis. The

aperture of a mirror is the number of degrees in a principal section of it.

61. A pencil of rays incident on a spherical reflector will not all converge to a geometrical point after reflexion, but will be diffused over a considerable surface, called a *caustic surface.* When, however, the aperture of the mirror is small, or when the part of it on which the pencil falls is small, the focus will be reduced to at least a very small space, which may be considered as a point.

62. When a pencil is so small that its extreme rays have very little inclination, the point towards which they converge is called the *geometrical focus* of the reflected rays. If the small pencil is cylindrical, that is, if it consists of parallel rays, or, in other words, if the radiant point is very far distant, and if the pencil be nearly perpendicular to the surface of the mirror, the focus in this case is called the *principal focus* of the mirror.

63. Thus if R is a radiant point on the axis of the mirror, and I the point of incidence of an extreme ray of the divergent pencil, the radius C I is a normal to the surface; and if I F be drawn so that the angle C I F of reflexion is equal to the angle C I R of incidence, then F will be the geometrical focus of reflected rays, if the aperture I V is small. Also if a small pencil of parallel rays whose axis coincides with R V the axis of the mirror, converges, after reflexion, to the point P, it is the principal focus of the mirror.

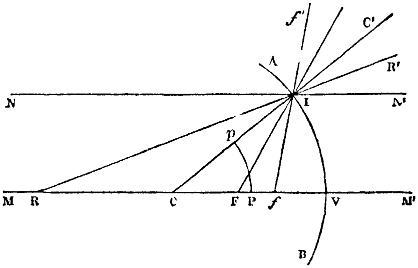

Fig. 14.

64. The radiant point R and its corresponding focus F of reflected rays are called also *conjugate foci.* The distance of the focus from the vertex V is called the *focal distance,* as F V; and the distance between the principal focus and the vertex is called the *principal focal distance,* or merely the

focal distance of the mirror. The distance of any two conjugate foci on the axis from the vertex of the mirror are called *conjugate focal distances.* Thus R V, F V are conjugate focal distances for the radiant point R and the focus of reflected rays F.

Cylindrical Direct Pencil.

65. The first or simplest case of reflexion is when the pencil is cylindrical (that is, when it consists of parallel rays), and is also direct (that is, when its axis is perpendicular to the surface of the mirror). In this case it passes through the centre.

66. The principal focus of a spherical mirror, whether concave or convex, is on the axis, at the distance of half the radius from the centre; or it is the middle point between the centre and the vertex.

67. Let R V (fig. 14), be the axis of the pencil, and N I one of the extreme rays incident at I on the spherical mirror A V B; then since the reflected ray I f makes the same angle with the normal or radius I C that the incident ray N I does, the angle C I f is equal to C I N; but I N is parallel to M V, and hence the alternate angles C I N and I C F are equal,* and consequently the angle C I f is equal to the angle I C f, and the line I f is equal to f C. Now when the arc or semi-aperture I V is very small, or the point I very near to V, the line f I will be very nearly equal to f V, and f I is exactly equal to C f, therefore f V is in that case equal to f C. If therefore P be the middle point between C and V, the point f will, as the arc I V diminishes, approach indefinitely near to F as its limiting position; that is, P the middle of the radius C V is the geometrical focus of direct parallel rays, or it is the principal focus of the mirror.

68. When the mirror is convex, the very same reasoning applies, for A V B being the convex mirror, M′ V would be the axis of the incident pencil of parallel rays, N′ I one of the extreme rays, C′ I the normal, I F′ the reflected ray; and the prolongation of these lines to the interior side of the surface would exactly correspond with the lines N I, I C, I F; and P therefore will be the principal focus of the convex surface.

69. EXAMPLE.—Let the radius of a convex or concave mirror be twenty inches, it is required to find the point which is its principal focus; that is, to determine the distance of this point from the centre C or the vertex V?

70. Since the principal focal distance is equal to half the radius, in this instance it will be equal to ten inches.

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* See the ELEMENTS OF PLANE GEOMETRY, book I. and prop. 29.

71. If several pencils of parallel rays are incident nearly perpendicular on a spherical surface, the foci of their reflected rays will lie in a spherical surface, whose centre is that of the mirror and whose radius is equal to half that of the mirror.

72. Thus if C I be a part of the axis of a second parallel pencil, its principal focus, as in the preceding case, is the point *p*, half way between C and I. Hence the points P *p* being equidistant from the centre C, are in a spherical surface, of which C is the centre; and the same can be proved of all other small direct cylindrical pencils, whose axes pass through the centre of the mirror. When the axes C V, C I, &c. of the incident pencils are in one plane, the principal foci P *p*, &c. are in the circular arc P *p*.

Divergent Direct Pencil.

73. When small diverging or converging pencils are directly incident on a spherical reflector, the principal focal distance is a mean proportional between the distances of the conjugate foci from the principal focus; or the distance of the focus of the reflected rays from the principal focus is a third proportional to the distance of the radiant point from the principal focus, and the half radius of the mirror.

74. Let A V B (fig. 14), be the reflector, R the radiant point, F the focus of reflected rays, P the principal focus, and C the centre; then C P, half the radius, is a mean proportional between P R and P F; that is, P R is to C P as C P to P F. As the points R, C, P are known, P R and C P are known, and P F can be found by simple proportion. Or if the square of C P be divided by P R, the quotient will be P F; and as P is the middle of the radius C V, if half the radius, namely, P V, be added to P F, the sum will be F V, the focal distance of reflected rays; or if the square of the whole radius be divided by four times the radiant focal distance, the quotient will be the reflected focal distance.*

75. This optical theorem may be stated also as a rule of calculation thus: Multiply together the radius of the mirror, and the focal distance of the radiant point, and divide the product by the difference between twice this focal distance and the radius, and the quotient will be the focal distance of reflected rays.

76. The rule may be stated still more simply in the following terms—observing that by the reciprocal of a number is

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* The terms radiant focal distance and reflected focal distance are merely elliptical expressions for the sake of conciseness, instead of—the focal distance of incident rays and of reflected rays.

meant one divided by that number; thus one-fourth is the reciprocal of four: the reciprocal of the radius is an arithmetical mean between the reciprocals of the conjugate focal distances.

77. **Example.**—Let the radius of the reflector C V be 4 feet, and the radiant focal distance R V 10 feet, to find the reflected focal distance F V?

78. In this instance CP is 2, PR is PV diminished by CV, or 10 diminished by 2—that is, 8; and PR is to CP as CP to PF, or 8 is to 2 as 2 to PF; but 8 is to 2 as 2 to ½: hence PF is ½ foot; and if to it is added PV, or 2 feet, the sum is 2½ feet, which is the focal distance FV.

Convergent Pencil.

79. The same theorem and rules are equally true and applicable to the case where a convergent pencil is incident on a convex reflector. For R′V, N′I, being the principal, and the extreme rays of the convergent pencil falling on the convex surface AV B, and I F′ a reflected pencil, R′ and F′ will be as before—the one the radiant point, and the other the focus of reflected rays: hence the same rules apply. The conjugate foci are in this case imaginary.

80. The rule, with a slight change, applies also to the case of a divergent pencil incident on a convex mirror, or of a convergent pencil incident on a concave mirror. Let AVB be a convex mirror, and R′ the radiant point of a divergent pencil incident at I, then I C′ being a radius produced, and IF′ the reflected ray, the focus of reflected rays is F, and is in this case imaginary; the point P being as before the principal focus, the half radius C P is a mean proportional between P R′ and P F. The rules for the conjugate focal distances apply also to V R′ and V F.

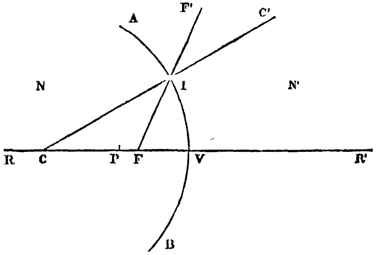

Fig. 15.

81. When AVB is a concave mirror, and RV, N I the axis and an extreme ray of an incident convergent pencil, then, producing N I to N′, it will be the focus of incident rays, or an imaginary radiant point, I F will be the reflected ray, and F the focus of reflected rays: this case is therefore exactly like the preceding.

82. In these four cases, either of the conjugate foci being considered the radiant point, the other will be the focus of reflected rays; for whatever path a ray pursues in passing from one point to another through any intervening media, it would also, in returning from the latter point to the former through the same media, pursue exactly the same path.

83. The conjugate foci lie on the same side of the principal focus in all the four cases.

84. When the position of the radiant point on the axis is changed, the position of the focus of reflected rays also changes, but in an opposite direction; that is, the conjugate *foci move contrary to each other: they also meet finally at the centre in the first two cases, and in the surface in the two* last cases. *Thus when R is removed farther from C, F will* also be more distant; for the angle RIC is increased, and so therefore is its equal angle of reflexion CIF. Also when R approaches towards C, F approaches also, and in C they ultimately meet. For exactly a similar reason in the two latter cases, when R′ moves farther away from V, F moves from V towards P; and consequently when R′ moves towards V, so does F, until at last both meet in V.

Change in the Vergency of Rays by Reflexion.

85. By the *vergency* of the rays of a pencil is meant the degree of their tendency to or from one another; that is, the degree of either their convergency or divergency. An increase in the convergency, or a decrease of divergency, is a *positive* change of vergency; the contrary effect—that is, a decrease of convergency, or an increase in divergency—is a *negative* change of vergency.

86. Reflexion by a concave mirror causes a positive change in the vergency of incident rays; and by a convex mirror the change is negative. In other words, a concave mirror diminishes the divergency, or increases the convergency of incident rays; and a contrary effect is produced by a convex mirror, which increases the divergency, or diminishes the convergency.

Aberration of Sphericity.

87. It has been stated above, that when an incident pencil is not very small, its rays do not converge to the same point. Thus if F (fig. 16) is the geometric focus of reflected rays, and A*f* an extreme ray, then all the intermediate rays converge towards points between F and *f*, or they will cross the axis in various points between F and *f*.

88. The distance between the geometrical focus and the focus

of an extreme ray of the same reflected pencil, is called the *longitudinal aberration;* as F f.

89. The perpendicular to the axis of the mirror from the geometrical focus of reflected rays produced, to meet an extreme ray, is the *lateral aberration;* as F L.

90. As the species of aberration here mentioned is what is produced on light of one colour, by the mere *form* of the reflector, and as that form is spherical, it is therefore termed *aberration of sphericity.*

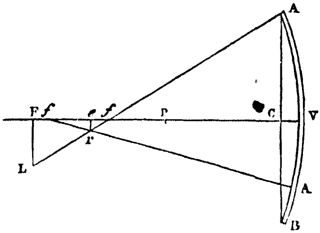

Fig. 16.

Reflexion without Aberration.

91. Light proceeding either from an indefinite distance, or from a point—that is, either parallel or vergent rays—can be accurately reflected to a point by the following methods :—

92. When the incident pencil consists of *parallel* rays, proceeding in the direction R G parallel to the axis X V of a concave mirror A V B, of a parabolic form, any ray, as R G, will be reflected at G in the direction G F, to the geometrical focus F of the parabola.

93. This optical property of the mirror, formed by the revolution of the parabola A V B about its axis X V, depends on the geometrical property of the parabola, that the angles H G R, E G F contained by the tangent H E, and by a line R G parallel to the axis, and another G F to the focus, are always equal; and these are just the angles of co-incidence and co-reflexion.

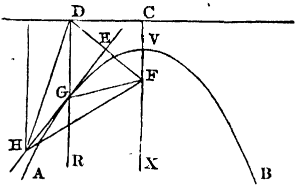

Fig. 17.

94. *Vergent* rays may be reflected to a focus by means of a reflector E D F (fig. 18), the figure of which is formed by the revolution of an ellipse E D F about its greater axis E F; the foci being A and B.

95. For when the rays are divergent from one focus A, any incident ray A D is reflected at D in a direction D B to the other focus B; for it is a property of the ellipse that the tan-

gent R N makes equal angles A D R, B D N with lines D A, D B drawn from D to each focus.

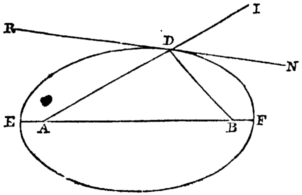

Fig. 18.

96. If the rays are convergent, and fall on a *convex elliptical mirror, the imaginary focus of the convergent pencil being* at one focus of the ellipse, they will be reflected in a divergent pencil having an imaginary focus in the other focus B of the ellipse. For if I D be one of the incident rays, it will be so reflected that the prolongation of the reflected ray would be in the direction D B.

97. *Vergent* rays can also be reflected exactly to a focus when the mirror is of a hyperbolic form, or generated by the revolution of a hyperbola, D F D′, about its axis A B, whose foci are the points A and B.

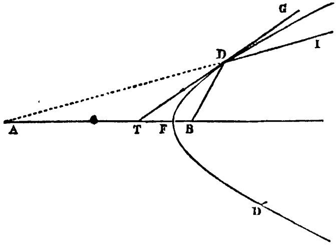

Fig. 19.

98. For if the focus of a divergent pencil be in B, any ray B D, incident on the concave surface, would be reflected in the direction D I; the extension of which would pass through the focus A, which would thus be the imaginary focus of the divergent reflected pencil.

99. Again, if A be the focus of a divergent pencil incident on the convex surface at D, it will be reflected so that its direction, if produced, would be D B; and thus B would be the imaginary focus of the reflected divergent pencil.

100. The three preceding curves are called the *conic sections*, and the mirrors may be called mirrors of revolution of the conic sections.

FORMATION OF IMAGES BY REFLEXION.

101. As in the case of the formation of images by plane mirrors, explained above, so in reflexion by curved surfaces, the rays proceeding from any point in the object, after reflexion, converge towards a focus, which is the image of

the original point; and thus the rays from every point of the object form images of these points, the assemblage of which constitutes the entire image of the object. In the case of spherical mirrors, it is evident that the pencil of rays proceeding from any point of the object is conical, the point being the apex of the cone, and the surface of the mirror its base; and the reflected pencil is a similar cone, whose apex is the focus of the reflected rays. Also, since the reflected rays corresponding to the incident rays from any point of the object, when convergent, cross each other at the reflected focus, and then proceed, in the form of a divergent pencil, from a point of the image; and as the same is true for every point of the image, it is manifest that rays proceed from it in the same manner as from any real object: the image, therefore, will be seen as if it were a real object by an eye so situated as to receive a sufficient number of the rays proceeding from it, as in the case of images formed by a plane mirror.

102. When the object is a circular arc concentric with the mirror, so is the image.

103. Let G′C′H′ be the object, having for its centre the point O, which is also the centre of the mirror A V B; then I C H, its image, is also a circular arc, having the same centre.

104. For the distances of every point in the object, as H′ D, G′ G, from the mirror are all equal; and hence the distances of their images H D, I G from the mirror are equal; and hence the image is a circular arc I C H, having O for its centre.

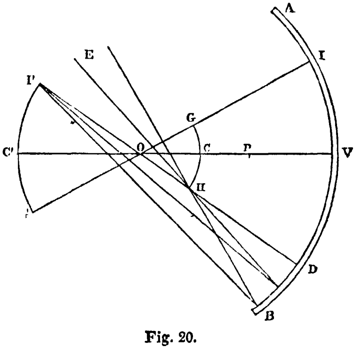

Fig. 20.

105. Rays proceeding from any point H′ of the object, to any portion D B of the mirror, are reflected to a point H, and there cross each other, and then form a divergent pencil proceeding from H; and on entering an eye placed at E, they produce a sensation of the point of the object, just as if G H were the original; and thus the image, though immaterial, existing only in vacant space, a mere visible, but not a tangible object, produces the same sensation and perception as if it were a material object. If P be the principal focus,

the position of the point C, the image of C′, is found by the proportion C′ P is to O P as O C′ to O C; and the first three terms are known, consequently the fourth can be computed by simple proportion.

106. The magnitudes of the object and image are proportional to their distances from the centre; that is, the size of the line G′C′H is to that of its image G′C′H, as the distance OC′ to OC; for these arcs are the same divisions of the circumferences of the circles of which they form a part; and hence their magnitudes are as the radii of the circles OC′, OC.

Image of a Straight Line.

107. The image of a straight line is a conic section, being either an ellipse, a parabola, or a hyperbola.

108. Let M O R be the object, A V B the mirror, C its centre, and *m o r* the image, it is a portion of a conic section. Make C D equal to C O, and D H perpendicular to the axis O V. Bisect C G in P, and it is the principal focus for a ray in the direction R C, and *r* the geometrical focus for the point R; that is, its image is found by the proportion R P is to C P as C R to C *r*, as in the preceding article the point C was found. In the same manner the points *o*, *m*, the images of O, M, are found.

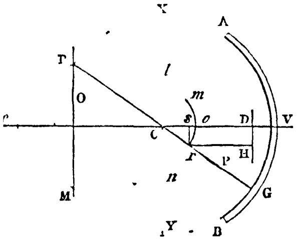

Fig 21.

109. But the image *m o r* can be more readily found from the fact that it is a portion of a conic section, of which the line D H is called the directrix, and the centre C a focus; and any point whatever in it, as *r*, is found from the proportion C D is to C P as H *r* or D *s* to C *r*; and as C D, C P are known and invariable, and D *s* or H *r* is assumed, the fourth proportion C *r* corresponding to it can be found, and hence also the point *r* is found. In the same manner the other points of the image are found.

110. If *l* C *n* be drawn perpendicularly to the axis, and the mirror be extended to the size of a semicircle limited at X and Y by *l n* produced, then the straight line M R being considered unlimited in length, its image produced by reflexion at the concave surface of the mirror is *l m o r n*, and the other portion *l e n* of the image is that produced by reflexion at the convex surface of that half of the mirror, considered as a com-

plete spherical shell, which, if continued, would lie between X Y and M R.

111. When the line C D equal to *c o* is *greater* than C P, the image *l o n e* is an *ellipse*, as represented in the figure; when C D is *equal* to C P, the image is a *parabola*, whose vertex cuts O V, and whose axis coincides with that of the mirror; and when C D is *less* than C P, the image is a *hyperbola*, its vertex and axis having positions similar to the parabolic image.

112. The *curvature* of the image of a straight line, perpendicular to the axis of a spherical mirror, and short compared with the radius of the mirror, is *invariable;* and the same is true of a small circular plane perpendicular to the axis of the mirror; its image will be very nearly a portion of a sphere whose radius is half that of the mirror: a screen, therefore, of this form would receive an accurate image of the object if its surface could be made to coincide with the image. If the line be far distant, or if it be small when near, its image being small, will not sensibly differ from a straight line.

113. Images are seen in convex mirrors by means of the reflected rays in a manner similar to those seen in plane mirrors; they appear to be *within* the spherical surface.

114. Sound and heat are capable of reflexion in a manner similar to light.

115. Since the image of the point R is at *r*, if *r* were a small object, its image would be at R, and by an eye properly situated would be seen farther from the mirror than *r*, and not far out of the direction of the ray *r* R. Since, however, the image is inverted, in order to see it erect, the object at *r* would require to be inverted.

CATOPTRICAL ILLUSIONS.

116. Many catoptrical illusions may be produced by the use of a concave spherical mirror. When the object is placed farther from the mirror than its principal focus, the image is always in front of the mirror, and, under favourable circumstances, it will appear to be situated in the air. This is particularly the case when the object is strongly illuminated, and concealed from the spectator, and when, at the same time, the mirror is invisible by being placed in the dark—as when the object and mirror are in a dark chamber, near a partition in which is a convenient opening for the reflected rays to pass through. The image may also be exhibited on dense light-coloured smoke, as that of frankincense; and if the optical arrangements are unknown to the spectator, the effect appears to be magical.

DIOPTRICS

OR THE REFRACTION OF LIGHT.

117. In the refraction, as in the reflexion of light, the angle contained by the incident ray and the normal is called the *angle of incidence;* but that contained by the refracted ray, within the medium and the normal, is called the *angle of refraction.*

118. Thus if T U X Y be a transparent medium, the ray R I moving in a different medium, as air or a vacuum,[*] and incident at I, will, on entering it, move in some direction, I F, different from I V or R I produced. The ray I F thus appears to be *broken* or *refracted.* R I being the incident ray, I F the refracted ray, and P N the normal at I to the surface T U, R I N is the angle of incidence and F I P that of refraction.

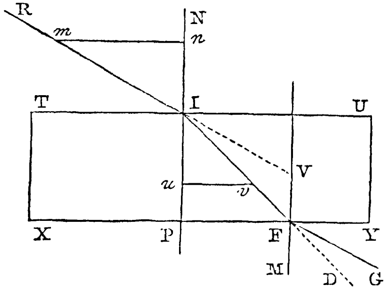

Fig. 22.

119. If the distances Im, Iv, or the incident and refracted ray, be made equal to some *unit of length*, then Im, Iv are each 1; and the *numbers* denoting the lengths of the perpendiculars mn, vu upon the normal N P, are called the *sines* of the angles of incidence and refraction R I N and F I P. These sines are always less than 1; or they will always be proper fractions when the incident ray is in air. The angle contained by the deviations of an incident and a refracted

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[*] Generally, incident rays are understood to be moving in air, unless the contrary be expressed. The refractive power of air is so small, that for ordinary purposes it may be considered as nothing.

ray, is called the *angle of deviation;* thus F I V is the angle of deviation. The angles contained by the incident and refracted rays with the refracting surface may be called the angles of *co-incidence* and *co-refraction;* these are the angles R I T and F I U.

120. The plane in which the incident ray and the normal lie is called the *plane of incidence;* this plane is R T N. The angles of incidence, refraction, deviation, co-incidence, and co-refraction, all lie in the plane of incidence, considered to be extended.

121. In different substances used as media, the angles of deviation for the same angle of incidence are different, which proves that they have different refractive powers. In general, the denser bodies are, the greater their refractive power.

122. The sines of the angles of incidence and refraction for the same medium are always in a fixed proportion; that is, the sine of one angle of incidence is to the sine of its corresponding angle of refraction as the sine of another, though different angle of incidence, is to the sine of its angle of refraction.

123. If, for example, mn were $\frac{4}{5}$, and uv $\frac{3}{5}$, then mn would be to uv as $\frac{4}{5}$ to $\frac{3}{5}$, or as 4 to 3. Again, if the angle R I N were reduced so that its sine mn were only $\frac{4}{9}$, then would uv be only $\frac{3}{9}$ or $\frac{1}{3}$; for since the two former sines are as 4 to 3, the two latter must be to one another in the same proportion; or 4 is to 3, as $\frac{4}{9}$ to $\frac{3}{9}$ or $\frac{1}{3}$.

124. If, therefore, the sines of an angle of incidence, and of its corresponding angle of refraction for any medium are known, the sine of the angle of refraction corresponding to any other angle of incidence can be found by proportion. But this is more easily obtained by the following considerations:—

125. The sine of an angle of incidence being divided by the sine of its corresponding angle of refraction, the *quotient* is called the *index of refraction*, or the *refractive index*, for that medium. Thus in the above case the sines were $\frac{4}{5}$ and $\frac{3}{5}$, and the former being divided by the latter, gives the fraction $\frac{4}{3}$. This, then, is the refractive power of the medium, and is the exact number for fresh water. If, therefore, the sine of the angle of incidence, when water is the refracting medium, be known, the sine of the angle of refraction will be found by dividing the former by the refractive index of water—that is, by $\frac{4}{3}$; or, more simply, by multiplying it by $\frac{3}{4}$.

126. EXAMPLE.—If the sine of the angle of incidence in water be $\frac{3}{8}$, what will be the sine of its angle of refraction? Here $\frac{3}{8}$ is to be multiplied by $\frac{3}{4}$, which gives $\frac{9}{32}$, or nearly $\frac{2}{7}$.

If, therefore, when *m n* is $\frac{3}{8}$, *u v* be made $\frac{2}{7}$, the line I *v* will be the direction of the refracted ray.

127. When a ray passes from one medium into another of greater refractive power, the index of refraction is always greater than 1; but conversely, when it passes into a medium of less refractive power, the index is less than 1. The index of refraction from air into water was stated above to be $\frac{4}{3}$; that from air into *crown-glass* is $\frac{3}{2}$; and since $\frac{4}{3}$ is to $\frac{3}{2}$ as 8 to 9, the refractive powers of these two media are as 8 to 9.

128. If a ray proceeding from a given point in air enter a different medium, as water, and be refracted to a given point; a ray proceeding from this latter point backward in the direction of the refracted ray will be refracted again on coming into the air exactly in the direction of the first incident ray, and will proceed to the first point; and in general a ray proceeding from one point, and, after any number of refractions, reaching another point, will, in leaving this point in the direction of the last refracted ray, retrace exactly the same path in an opposite course, and will reach the first point.

129. The same law holds for curved surfaces, the angles of incidence and refraction in these being the same as for a plane surface touching the curved surface at the point of incidence.

130. When a ray is incident perpendicularly on a refracting surface, it enters the medium without change; for the angle of incidence being nothing, so is the angle of refraction, and the refracted ray consequently coincides with the normal.

131. When a ray passes through a refracting medium, and then leaves it in passing into the air, it is said to *emerge*, and is called an *emergent ray*.

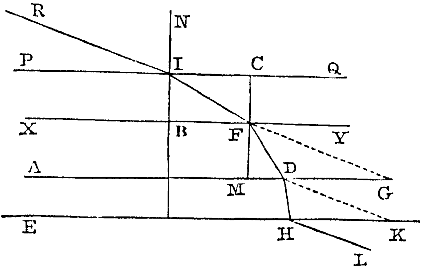

Fig. 23.

132. When the two plane surfaces bounding a transparent medium are parallel, the course of the emergent ray is parallel to the incident ray.

133. Thus let R I be a ray in air incident on the transparent medium P Q X Y; after being refracted in the direction I F, it will emerge from the medium into air included in the

space X Y A G, in the direction F G, which is parallel to R I, the incident ray. For if the ray were an incident ray within the surface in the direction F I, it would proceed in the line I R by art. 128; now the surfaces P Q, X Y being parallel, the alternate angles B I F, I F C are equal; that is, the internal angle of incidence at F—namely, I F C—is the same as the angle of incidence at I were the ray moving in the direction F I; hence the external angle of refraction M F G must be equal to the angle of external incidence R I N; and since the normals I N, F M are parallel, the rays F G, R I must also be parallel.

134. Hence if a ray has traversed several different media bounded by parallel surfaces, its direction through the last is the same as if the other media had not intervened, though its actual position is not the same.

135. Thus since the ray emergent into air at F is in the direction E G, if the space X Y A G is, instead of air, some other transparent medium, as crown-glass, the ray emergent from the first medium P Y, instead of proceeding in the direction E G, will be refracted in the direction F D, the same as if the first ray R I had been incident at F, in a direction parallel to R I. Now the ray emergent at D would proceed in air in the direction D K, also parallel to F G or R I; but if the space A G E K be supposed to be a third medium, as flint-glass, the ray incident on it at D is refracted in the line P H, and emerges into air in a direction H L, parallel to the original direction R I.

136. Hence the remarkable inference is deduced that, "when a ray incident from any medium, as air, traverses successively any number of transparent media of different refractive powers, bounded by parallel plane surfaces, and finally emerges from the last into a medium the same as the first, its direction is parallel to its direction of incidence."

137. If the index of refraction from air into any medium be divided by the index for another medium, the quotient will be the index of refraction for a ray from the latter medium into the former.

138. Example.—The index of refraction for air and water is $\frac{4}{3}$; for air and crown-glass $\frac{3}{2}$; and $\frac{3}{2}$ divided by $\frac{4}{3}$ gives the quotient $\frac{9}{8}$, which is therefore the index of refraction from water into crown-glass; that is, if P Y be water, and X G crown-glass, and a ray I F in water be incident at F on the glass, then the angles of incidence I F C, P F M are such that the sine of the former is to the sine of the latter as 9 to 8.

139. One effect of refraction is to cause the apparent elevation of objects. Let *a* (fig. 24) be a small object, as a piece of

coin, in the bottom of a basin, and let the eye be so situated at C that the coin is just out of sight; then if the basin be gently filled with water, so as not to disturb the coin, it will, by the influence of refraction, be seen in the direction of the line CD at *b*. For the rays from the coin on entering the air, which has a much less refractive power than the water, are turned away from the perpendicular towards the surface of the water; and of all the pencils so emerging, some one will proceed to the eye, and the image of the coin will appear in the direction of this pencil, and will be elevated and brought into sight.

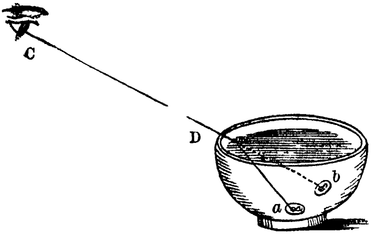

Fig. 24.

140. From the same cause, objects in the bottom of a river appear higher than they are, and the water seems to have less than its real depth. If C D *b* were a straight rod, the portion of it, D *b*, immersed in the water, would appear in the position D *a*, as if the rod were broken at D.

141. Let D I M N be any medium bounded by a plane surface D 1, and let R be a radiant point, and R D and R I two incident rays of a divergent pencil proceeding from R to the surface of the medium; then R D, being perpendicular to the surface, suffers no refraction, but is continued along D M within the medium; but the ray incident at I is refracted into the direction I N, which produced outwards, meets the normal D F in F. Therefore a small pencil of rays proceeding from R, and having the axis R D perpendicular to the surface, will be refracted into another pencil diverging from the imaginary focus F; for all the rays intermediate between R D and R I will converge very near F when the pencil is of small extent.

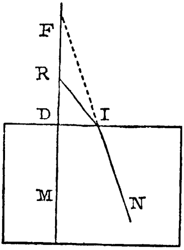

Fig. 25.

142. If an eye were situated between N and M within the medium, these points being supposed very near, a point R would be seen by means of the refracted rays apparently

diverging from F, and therefore it would appear to be *more distant.*

143. Again, if the radiant point be situated within the refracting medium, as at R, the perpendicular R D M being the axis of the pencil, and R I an extreme ray incident at I; when the ray emerges into air it is refracted in the direction I N, farther from the perpendicular, and its direction produced backwards cuts the axis in F, the focus of refracted rays. Now the pencil being supposed very narrow (such a pencil as would be all taken in at once by the eye), the ray I N would, as in the preceding case, lie near to D M, and to an eye situated at M, the point R would be seen by means of a pencil of rays apparently radiating from F. In this and in the former case, the distance D R is to D F as the sine of refraction to the sine of incidence.

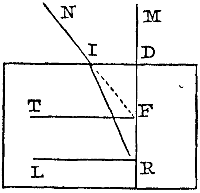

Fig. 26.

144. Example.—If the medium be water, and D R 10 inches, find the distance D F: 4 is to 3 as 10 to DF; hence D F is 7½ inches.

145. In the former of the two cases, the focus of refracted rays, when water is the medium, is always *farther* distant from the surface than the radiant point by *one-third* of the distance of the latter; and in the latter case it is *nearer* by *one-fourth* of that distance.

146. A stone at the bottom of a pool of water 12 feet deep appears 3 feet higher up, or at the depth of only 9 feet. A straight bar of wood lying obliquely in water would have every part of it apparently elevated one-fourth of its depth; the lower end would appear thus to be elevated in a greater degree than the other end, so that the image would seem *less inclined* to the horizontal line than the real bar.

147. If crown-glass were the medium instead of water, the numbers 3 and 4 would have to be changed into 2 and 3; and the expressions one-third and one-fourth into one-half and one-third.

CRITICAL ANGLE OF INTERNAL INCIDENCE—TOTAL INTERNAL REFLEXION.

148. When a ray of light, within a medium bordering upon air, is incident on the internal surface, at an angle amounting to or exceeding a certain size, the ray is then incapable of

emerging into the air, and it is reflected internally at the surface according to the ordinary laws of reflexion. The angle of internal incidence at which this remarkable effect takes place is called the *critical* angle, as it is the limit to the emergence of a ray; and all the light beyond this angle that falls on the internal surface undergoes *total reflexion.*

149. The critical angle is such that the rule of the sines would give the sine of refraction into air equal to the radius, or 1; now an angle whose sine is 1 is a right angle; but the angle of external refraction could not exceed a right angle; that is, if R I be a ray incident on the internal surface C D of a medium P Q D C, the angle E I N of refraction cannot exceed the angle C I N.

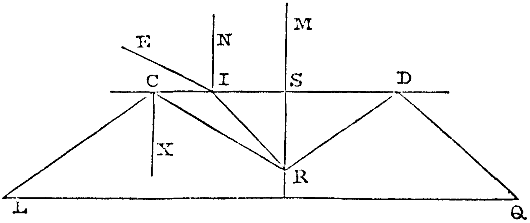

Fig. 27.

150. Thus to find the critical angle of refraction for water: Let the ray R C be incident at such an angle R C X that the sine of external refraction would be 1; then by the laws of sines the sine of refraction is to that of incidence as 1 to the sine of the critical angle R C X, or 4 is to 3 as 1 to the sine of R C X; hence this sine is $\frac{3}{4}$ or ·75; and from a table of natural sines,* the angle of which this is the sine is 48 degrees 36 minutes—that is, 48° 36′.

151. When, therefore, the angle R C X exceeds 48° 36′, there can be no emergence or no refraction; the ray is reflected back within the medium in the direction C L, making the angle of reflexion L C X equal to that of incidence R C X. As no ray can emerge when the internal incidence exceeds the above limit, there is therefore a total reflexion for upwards of 40°.

152. If we fill a tumbler with water, and place the eye in a position somewhat lower than the surface of the water, objects situated beyond the tumbler will be seen by reflexion at the

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* See MATHEMATICAL TABLES of "Chambers's Educational Course."

internal surface, as if it were a plane mirror of the finest polish.

153. When the eye is immersed in smooth water, as at R, the external objects around will all be seen through a limited circle on the surface of the water, of which C D is the diameter, S D being made equal to S C; for it is only the external rays incident on some point of the surface of this circle that can reach the eye. But objects situated at the bottom of the water beyond the points L and Q, will be seen by internal reflexion at the surface. The diameter of the circle will be $1\frac{1}{3}$ times the depth of the eye below the surface; so that if the eye is 3 feet below the water, the diameter of this circle will be 4 feet.

154. For crown or plate-glass the ratio of the sines of incidence and refraction is in the case of emergence 2 to 3; when, therefore, the angle of refraction is a right angle, or its sine is equal to 1, that of incidence is $\frac{2}{3}$ or ·666, and the angle of which this is the sine is 41° 48′. The index for flint-glass is $\frac{11}{6}$, and the angle whose sine is $\frac{6}{11}$ is 33° 3′. Hence, in the former case, total reflexion will take place over more than 50°; and in the latter, for nearly two-thirds of the whole range of a right angle.

REFRACTION BY PRISMS.

155. The only case of compound refractions yet considered is that of a medium bounded by two plane parallel surfaces. We shall now take up the case of a medium bounded by two plane surfaces making an angle; such a medium is called a *prism*.

156. The angle contained by the two refracting sides of a prism is called the *refracting angle*, or *vertex*, as V; and A V, B V, the refracting sides, are called the *faces* of the prism. The line in which the faces meet is called the *edge* of the prism; and a section by a plane perpendicular to the edge is called a *principal section* of it, as A B V. The medium is supposed to be much denser than air—as water, glass, &c.—and to be surrounded with air.

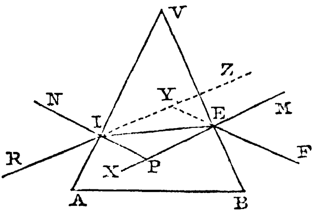

Fig. 28.

157. When a ray is refracted by passing through a prism, the deviation of the emergent ray is always from the vertex. If the ray R I be incident at I, on the lower side of the normal I N, the refracted ray I E is on the upper side of the prolongation I P of the normal, and the emergent ray E F on the lower side of the normal E M. The deviation is the angle made by the incident and refracted rays R I, E F, when produced to meet at Y.

158. If the refracting angle of any prism *exceeds* the double of the critical angle corresponding to the medium, no ray can be transmitted through it; so that it will appear *perfectly black* if no rays enter at the third surface A B, or are reflected there. For crown-glass, this refracting angle of the prism is twice 41° 48′, or 83° 36′.

159. An eye placed at F would see an object at R in the direction F E Y of the emergent ray, instead of the direction F R. The angle of deviation of the incident and emergent rays R I, E F, is the angle E Y Z; and it is found to be the least possible in any one prism, when the angles of incidence and emergence R I N, F E M, are equal. When these angles are equal and known, and when the refracting angle also is known, the refractive power of the material of the prism can be found.

160. The *camera lucida* is an optical instrument useful in the delineation of complicated objects: it is the invention of Dr Wollaston. A B K C is a four-sided prism, represented on a principal section; it is a right angle; B and C are each 67° 30′, and K the double of this, or 135°. The side A B is directed towards an object, and the eye at E is so situated that both the rays from the object, and those from the paper lying horizontally at M N, may be seen at the same time.

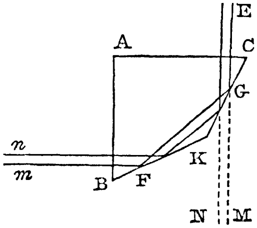

Fig. 29.

ATMOSPHERIC REFRACTION.

161. The apparent elevation of a terrestrial object caused by the bending of the rays of light in their passage through the atmosphere, is called *atmospheric refraction.* When the density of the atmosphere varies from its ordinary state, the *unusual* refraction thus arising produces various phenomena.

162. Distant objects, not usually visible, from their being below the horizon, become visible, and sometimes appear to be nearer and larger. This arises from a sudden change in the density of the atmosphere.

163. The cliffs on the coast of France opposite to Hastings are sometimes visible there, although they are usually below the horizon of the place, and fifty miles distant. The French coast then appears so distinct that known places can be distinguished. The sailors on board a vessel that was detained by the severity of the winter at Nova Zembla, observed the sun above the horizon, when by calculation it was found to be 4°, or about 8 times its own diameter, below it.

164. An object is sometimes seen apparently inverted. This phenomenon happens when the density of the strata of air next the earth is less than that of the stratum immediately over it. Such an uncommon state of density happens daily on sandy plains exposed to the intense heat of the sun, which raises the temperature of the earth's surface, and rarefies the air up to a certain height, where the stratum of greatest density comes to be situated, instead of being as usual at the earth's surface.

165. If the object that suffers the inversion be detached, the sky beyond it will also have its image much lower, and will produce the appearance of a lake lying below the erect image, and above the inverted one. This illusion, occurring in arid deserts, and termed the *mirage*, deludes the traveller with the hope of finding water; but as he approaches, it continually recedes, and at last disappears, when the real objects, houses and villages, are distinctly seen by means of the direct light.

166. When, from an increase in the temperature of the air near the earth's surface, the density is nearly uniform to a small height above the spectator, while above this limit the ordinary rarefaction takes place, besides the ordinary image of a distant object seen by the direct rays, there is another inverted image higher up, which is caused by the reflexion of rays that ascend from the object, and reach the above limit in a nearly horizontal direction, and are then by total reflexion turned down towards the spectator. The effect is precisely the reverse of the foregoing.

167. In all cases when there is a sudden change in the density of any strata of a refracting medium, rays reaching it at a very small inclination undergo reflexion, and produce images similar to those of a plane mirror, inverted, not in the horizontal dimensions, but only in the vertical.

168. It sometimes happens that an erect image is observed above the inverted image. This happens when the density

of the air diminishes upwards more rapidly than usual. This image is sometimes seen along with the inverted image, when the object is too far distant to be seen by means of the direct rays. Captain Scoresby has *frequently observed the phenomenon in the Arctic Seas, and has even recognised his father's* ship by means of the image of it suspended in the air.

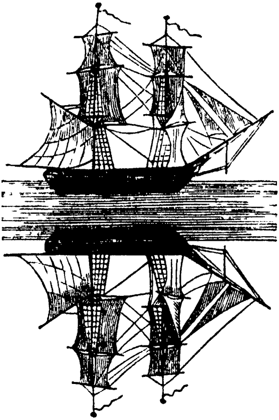

Fig. 30.

169. The object, when a ship, is seen generally along with a portion of the sea, and so near that the erect and inverted images of it are in contact. This is illustrated in the annexed cut of the elevated, inverted, and erect images.

170. These remarkable effects of unusual refraction may be illustrated by experiment. If, for instance, a bar of iron is heated, and laid in a horizontal position, the air in contact with its upper surface will be rarer than that at some distance above it, and thus the order of density will be to a small height inverted; consequently, in looking horizontally along the bar to an object at a little height above it, its *direct* image will be seen by means of horizontal rays, and an *inverted* image will be seen *below* it by reflected rays.

171. A similar appearance may be observed by filling a vessel, A B C D, with a solution of common salt or sugar, with pure water over it. This will form a medium which suddenly changes its density upwards, and if the ends at O and E are glass, an object at O will be seen *directly* by the horizontal rays O E, and an *inverted* image will be seen *above* it in the direction E *s*, by means of rays O *s* E reflected in passing from the dense to the rare medium.

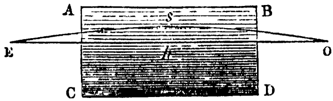

Fig. 31.

REFRACTION AT SPHERICAL SURFACES.

172. In treating of refractions at spherical surfaces, the

medium is considered to be much denser than the surrounding air. We shall consider first the refraction at *one surface, and* then proceed to combined or successive refractions :—

Refraction at a Single Spherical Surface.

173. "When *parallel rays* are refracted at a convex spherical surface, they are made to converge, and the distance of the geometric focus of refracted rays from the surface is to its distance from the centre as the sine of incidence to the sine of refraction."

174. Let A B Q P be a refracting medium, terminated by the convex spherical surface A V B, whose centre is C and vertex V (these points, and the surface in general being exactly analogous to the same parts of a convex spherical reflector), X V the axis of a pencil of parallel rays, and R I any other ray of it incident at I; then if C I N be a normal, the angle of refraction C I F will be less than the angle of incidence R I N, and the refracted ray will thus turn towards the axis, and will meet it at some point F. When the pencil is small, or the aperture A V B of only a few degrees, the rays will nearly all converge to the same point F. The two sides I F, C F of the triangle I C F are in the exact proportion of the sines of incidence and refraction, and with a small aperture, I F does not sensibly differ from V F; consequently, F V and F C, the distances of the focus F from the vertex and from the centre, are in the same proportion as the sines of incidence.

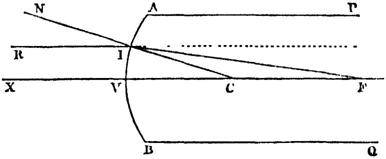

Fig 32.

175. Example.—When the medium is plate or crown-glass, the sines are as 3 to 2; wherefore the distances F V, C F are as 3 to 2; whence F V is to C V as 3 to 1, or V F is *three times the radius of the lens.* The distance F V is the principal focal distance of the surface.

176. When the rays of a cylindric pencil are incident nearly perpendicular on a *concave* spherical surface, they are made to diverge; their focus is imaginary, and lies without the medium on the same side as the incident pencil, and its distances from the surface and from its centre are in the same proportion as in the preceding case.

177. When the original pencil of parallel rays is *within* a

refracting medium terminated by a spherical surface, *convex* externally, or concave to the course of the rays, the focus of refracted rays is real, and lies without the surface; when it is concave externally, the focus is imaginary, and lies within the surface. In the former case, the refracted rays are convergent, and in the latter divergent; and in both cases the focus F and the centre C are on opposite sides of the vertex V.

178. The proportion as to the sines of incidence and refraction, and the distances of the focus from the surface and from the centre, holds in each of the four cases; only in the two latter, the incidence is within the medium, and the refraction without, and consequently the sine of incidence is less than that of refraction.

Vergent Rays.

179. When a *divergent pencil* has a nearly perpendicular incidence on a spherical surface, the distance of the radiant point from the principal focus of parallel rays proceeding *out* from the medium, the distance of the same point from the centre, its distance from the surface, and its distance from the geometric focus of refracted rays, are proportional.

180. Let M N U W be the medium, terminated by the convex spherical surface M V U, R the radiant point, I the point of incidence, F the geometric focus of refracted rays, C the centre, and P the principal focus for parallel rays in an opposite direction, or incident internally on the surface, then the distance R P is to R C as R V to R F, which gives the focus of refracted rays.

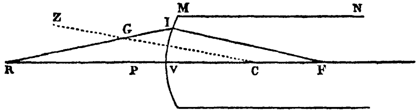

Fig. 33.

181. Example.—Let the medium be crown-glass, the radius 2 inches, and the distance of the radiant point from the surface, or R V, 12 inches; to find the focus F of refracted rays.

182. P V is twice the radius C V, or 4 inches, therefore R P is the difference of 12 and 4, or 8 inches; also R C is the sum of 12 and 2, that is, 14; hence the proportion R P to R C as R V to R F becomes 8 to 14 as 12 to R F; and R F is therefore 21 inches. If from the length R F, R V be taken away, the remainder is F V, the distance of F from the surface; now the difference between 21 and 12 is 9, and therefore F V is 9 inches.

183. In order to understand the nature of the refraction produced by a *lens* (which is a refracting medium bounded by *two* spherical surfaces), the following case may be premised.

184. When convergent rays within a medium are incident on a concave spherical surface, and refracted into air, the same relation exists among the various distances as in the preceding case.

185. Let M W be a refracting medium bounded by the surface I V U, and let the external medium be air; the latter is then bounded by a concave spherical surface I V U; let convergent rays within the first medium, of which G I, P V are two, have R for their imaginary focus; and after refraction at the surface, let the emergent rays converge to F as the refracted focus; then if C is the centre of curvature, R P is to R C as R V to R F; ' being the principal focus of rays incident in the opposite direction, or from air to the medium I V U.

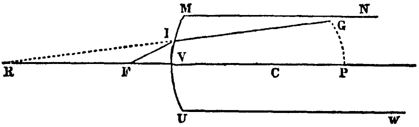

Fig. 34.

186. Example.—Let the medium be crown-glass, and let the radius C V be 3 inches, and the distance R V of the imaginary radiant point 9 inches; required the distance F R of the focus of emergent rays F from the radiant point.

187. Here C V is 3 inches, and P V is three times C V, or 9 inches; hence R V is 9 inches, R C is 12, and R P is 18, and the proportion R P to R C as R V to R F becomes 18 to 12 as 9 to R F; hence R V is 6 inches.

Aberration of Sphericity.

188. In the case of reflexion at spherical surfaces, it was shown that the rays do not all converge to one point; so in refraction a caustic surface is formed.

189. There is *one* radiant point for every single refracting surface for which there is *no aberration* of the refracted rays. This remarkable case will be understood by referring to fig. 35. M U′ is the medium, C the centre of the surface, and A V, B I are two rays of a pencil converging to R, which is thus an imaginary radiant point; B I is refracted into I F. Now if the point R be so chosen that R C is to C V as the sine of incidence to the sine of refraction, or as the refractive index to 1, the focus F of refracted rays will be found by making C V to C F as the sine of incidence to the sine of refraction;

and as the position of R is constant for the same medium, so is that of F, or F *is the same for every incident ray that converges to* F; so that all the incident rays unite in the *same point* after refraction, and there is thus *no aberration.*

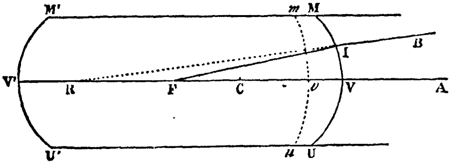

Fig. 35.

190. When there is no aberration of reflected or refracted rays at a surface, the surface is said to be *aplanatic;* and the combination of reflecting or refracting surfaces is called an *aplanatic combination.*

191. Were M V U a concave surface of a medium lying on the other side of it—that is, towards A—then rays incident from air from the point R would, after refraction, be divergent exactly towards a point F, when R C is to C V as above; that is, as the index of refraction from air is to 1.

192. An aplanatic refracting surface can also be formed by the revolution of an ellipse about its major axis. If the major axis be to the double eccentricity as the sine of incidence to the sine of refraction, then parallel rays incident on, or in the direction of the axis, will converge towards one of the foci. The revolution of a hyperbola of certain proportions about its axis will also produce an aplanatic surface.

193. A parabolic refracting surface possesses no peculiar property analogous to that of a parabolic reflector.

REFRACTION AT TWO SURFACES—LENSES.

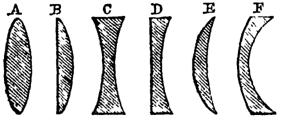

Fig. 36.

194. A *lens* is a refracting medium terminated by two spherical surfaces, either of which may be convex or concave. The annexed figure shows the different kinds of lenses.

195. A is a *double convex* lens, with two convex surfaces; B is *plano-convex*, one surface being plane, and the other convex; C is *double concave,* both surfaces being concave; D is *plano-concave,*

having one surface plane, and the other concave; E is a *meniscus*, one side of which is convex, and the other concave, and the two either meet as in the figure, or are such that, if sufficiently extended, they would meet; and F is a *concavo-convex*, but the convex surface has less curvature; that is, a greater radius than the concave one, and consequently they could not meet like the meniscus.

196. Besides these terms, the lenses sometimes receive other names that indicate which of the two surfaces is turned towards the incident light; the surface so turned being termed the *anterior* surface of the lens, while the other is the *posterior* surface. Thus if light were incident from the right hand on the lens F, its right side would be its anterior surface; and as it is concave, and the posterior surface convex, it is in this position called a *concavo-convex* lens; but if the light were incident from the left, the convex would then be the anterior surface, and it would be termed a *convexo-concave* lens. So the lens B would be called *plano-concave*, or *concavo-plane*, according as the light is incident on its plane or its convex side.

The Centre and Focal Centres of a Lens.

197. There is a fixed point within most lenses, but without some of them (such as the meniscus and concavo-convex), called its *centre*, from which the focal lengths are sometimes estimated when the thickness is considerable. This point can be found thus: let A B be the lens; C_1, C_2, the centres of its surfaces; draw any two radii C_1 E, C_2 G, parallel to each other, and join E G, and its intersection O with the axis M N is the *centre*.

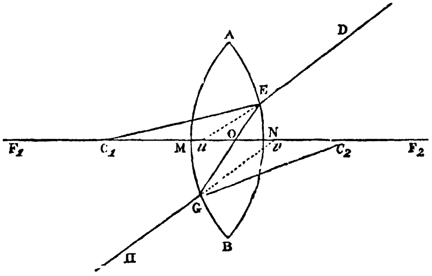

Fig. 37.

198. It is a remarkable property of the centre of a lens, that when any ray refracted by the lens passes through it, the incident and emergent portions are parallel. Thus if D E be an incident ray refracted in the direction E G, the emergent ray G H is parallel to D E. For the radii C_1 E, C_2 G

are parallel, and therefore the tangents to the curves at E and G being perpendicular to the radii, are also parallel; in other words, the surfaces at the points E, G are parallel, and the refraction in the direction E G is the same as through a medium limited by parallel sides.

199. The rule for finding the centre may be expressed thus: multiply the thickness of the lens by the radius of one surface, and divide the product by the sum of the radii, and the quotient is the distance of the centre from the vertex of that surface.

200. The position of the centre is the same in every lens of the same dimensions, whatever may be the material of which it consists.

201. In an equi-convex or equi-concave lens, it is the middle point of its axis M N.

202. In a plano-convex or plano-concave lens, it is in the vertex of its curved surface.

203. In the concavo-convex and meniscus lenses, the centre is without the lens; in the former beyond the concave, and in the latter beyond the convex surface.

204. The focal centres u, v, are found by the following proportion: F_1, F_2 are the principal foci of the two surfaces by a single refraction, as found by the method explained above; then $F_1 F_2$ is to $C_1 C_2$ as O N to O v; or the index of refraction is to the reduced index as the distance of the centre from either vertex of the two surfaces, to the distance of the centre from the focal centre next to that surface.

205. In a double convex lens of crown-glass, the index is $\frac{3}{2}$; and as the centre is in the middle, $\frac{3}{2}$ is to $\frac{1}{2}$, or 3 is to 1 as half the thickness to the required distance O v; therefore O v is $\frac{1}{2}$ of the thickness divided by 3—that is, $\frac{1}{6}$ of the thickness; and v N is $\frac{1}{2}$ the thickness diminished by $\frac{1}{6}$ of it; that is, $\frac{1}{3}$ of the thickness from the vertex N. The other focal centre u is of course at the same distance from the other vertex M.

206. In the plano-convex lens, the distance of the focal centre lying towards the plane side is at $\frac{1}{3}$ of the thickness from the vertex of the curved side, or $\frac{2}{3}$ of the thickness from the centre of the plane side. For the centre O of the lens is in the vertex N of the convex side, and O M becomes the whole thickness; therefore 3 is to 1 as the thickness to $\frac{1}{3}$ of it. For crown-glass the above rule is simply stated thus:—O v is $\frac{1}{3}$ of O N, and O u is $\frac{1}{3}$ of O M in all cases.

Parallel Rays.

207. When a lens is a complete *sphere*, its *principal focal distance*, if measured from the centre, is not found in the

same manner as in an equi-convex lens; for in finding the focal lengths of lenses the rule is not perfectly correct, though it is sufficiently precise for most practical purposes. The principal focal length in a sphere is found thus :—The excess of the index of refraction above 1 is to that index as the radius of the sphere to twice the focal distance; that is, twice the focal distance is equal to the product of the index of refraction, and the radius divided by the excess of the index above 1.

208. Thus, for glass, the index being $\frac{3}{2}$, its excess above 1 is $\frac{1}{2}$, and $\frac{3}{2}$ times the radius divided by $\frac{1}{2}$ is 3 times the radius; hence the focal distance is $1\frac{1}{2}$ times the radius.

209. Example.—Let the radius of the sphere be 2 inches, then the focal distance is $1\frac{1}{2}$ times 2 inches—that is, 3 inches; or the principal focus is an inch from the sphere.

210. When the index of refraction is 2, the focus is in the surface; and when the index exceeds 2, the focus is within the sphere.

Principal Focus of a Lens.

211. When a pencil, whether cylindrical, divergent, or convergent, is incident nearly perpendicular on the anterior surface of a lens, the rays are refracted within the medium into new directions; and when they reach the second surface on emerging into air, they are again refracted. The focus of the first refracted rays can be found as already shown for the case of refraction at a single surface, and this focus is to be considered as a new imaginary radiant point from which the rays are incident on the second surface; and the focus of the rays thus again refracted can be found in the same manner.

212. Thus let I H G L be a double convex lens, and R M, Q I, S H parallel rays of a *cylindric pencil* incident on it; and let it be required to find the focus F_2 of emergent rays after

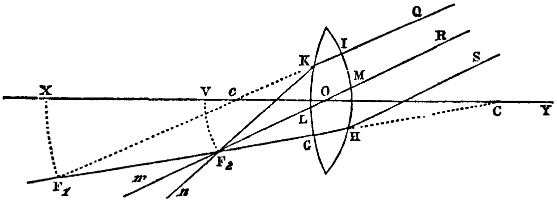

Fig. 38.

being refracted at the two surfaces of the lens. This point may be found by construction as follows:—Draw a figure of the lens, C and c being the centres of curvature of the two surfaces; and having found the centre of the lens O, draw the line $R\,O\,F_2$ through it parallel to the direction of the incident rays; then through C, the centre of the first or anterior surface, draw another line $Q\,c\,F_1$, parallel to $R\,M$; and the ray $Q\,F_1$ being perpendicular to the first surface, the focus F_1 of rays incident on it can be found. Join F_1 and c the centre of the second or posterior surface, and it will intersect the central ray $R\,F_2$ in the focus of the lens F_2.

213. To calculate $O\,F_2$, the following is the proportion:—The sum of the radius of the two surfaces is to the radius of the second surface as the distance of the first focus from the centre of the second surface, to the distance of the second focus from the centre of the lens.

214. When the incident rays are parallel to the axis $Y\,O$, the same rule for computation applies; and the foci F_1, F_2 are then in the axis $X\,Y$ of the lens; but the same method of construction would be inapplicable.

Images Formed by Lenses.

215. Of three cylindric pencils let $E\,E'\,E''$ be rays of the first, proceeding from some point of an object so distant that they may be considered parallel; $D\,D'\,D''$ rays of the second from another point; and $F\,F'\,F''$ from a third point; and let them be incident on the lens $A\,B$; these pencils after refraction will converge to the foci $G''\,G'\,G$, situated each on the central ray of its respective pencil. Thus images of the three points of the distant object are formed; and in the same manner pencils proceeding from the other points of the object form images of those points, and thus an image of the whole object will be formed in the principal focus of the lens.

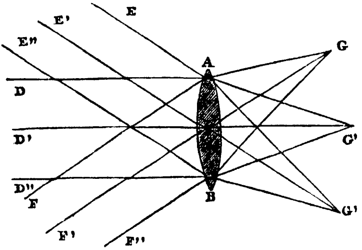

Fig. 39.

216. It is to be observed, that the principal focus of a lens, though merely a point for a cylindric pencil, is, in reference to all the parallel pencils that can fall on it, a spherical surface,

whose centre is nearly in the centre of the lens. An image, therefore, for parallel rays, is a portion of a *curved* surface.

217. The rule above given for determining the principal focal distance of a double convex lens, is also applicable to the double concave, the concavo-convex, and the meniscus lenses; only in the case of the two last the difference of the radii of the surfaces must be taken instead of the sum. It is further to be observed that the focal distance is to be measured from the surface of the lens next the focus. If the distance is required with more accuracy, it may be estimated from the centre of the lens, or, more accurately still, from the focal centre next to the focus.

218. There is an aberration produced by lenses, in the same manner as by refraction at a single surface. That form of lens which causes the least possible aberration with incident parallel rays, is a double convex, the radii of whose surfaces are to one another as 1 to 6; the more curved side being the anterior surface, and the material being crown or plate-glass.

Vergent Rays.

219. To find the *geometric focus* of rays refracted by a *sphere*, when the incident pencil is divergent. The proportion is as follows:—"The distance of the radiant point from the centre of the sphere, is a mean proportional between its distances from the principal focus of rays incident in an opposite direction, and from the focus of refracted rays."

220. For a *double convex lens*, when the thickness is inconsiderable, the rule is the same as for a sphere.

221. When vergent rays either converge to, or diverge from the centre, their vergency is not altered by refraction through the lens; but in every other case where vergent rays are incident nearly perpendicular on a convex lens, the lens increases the convergency, or diminishes the divergency, according as the incident pencil is convergent or divergent.

222. Since when parallel rays are incident on a lens, they are concentrated by refraction into the principal focus; so, on the other hand, when the radiant point is in the principal focus, the rays of the pencil proceeding in the opposite direction will emerge parallel.

223. If the radiant point is nearer a convex lens than its principal focus, and the pencil is divergent, the emergent rays are divergent, having their imaginary focus on the *same* side of the lens as the radiant point, but *farther* distant than this point. In the case when the radiant point is half-way between the lens and its principal focus. the imaginary focus of emer-

gent rays is in the principal focus; when the radiant point is still nearer the lens, the imaginary focus is nearer than the principal focus; but when the radiant point is farther distant than half, but less than the whole focal length, the imaginary focus is farther distant than the principal focus.

224. Let U V be a double concave lens, with convergent rays M O, N I incident on it, whose imaginary radiant point is R; and let the emergent rays meet in the geometric focus F, to find its position.

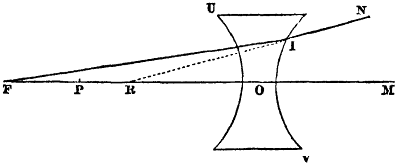

Fig. 40.

225. Find P the principal focus of rays incident in the opposite direction—that is, in a direction parallel to F O; then R P is to R O as R O to R F; so that as R P and R O are measured in opposite directions from R, so must R O and R F.

Compound Lenses.

226. The focal length of a compound lens can be found by means of the preceding rules; and as the object-glasses of good telescopes and microscopes are composed of two or more lenses, placed side by side, it is useful to know how to compute the focal distances of such combinations.

227. Let I C, E D be a convex and a concave lens combined together, required the principal focal length of the compound lens. Let R A, M I be two rays of a cylindrical pencil. In the first place, the principal focus P_1 of the convex lens IC has to be found; then all the rays proceeding from the second surface of this lens would converge towards P_1, were it not for the intervention of the concave lens; therefore a convergent pencil, whose virtual focus or radiant point is P, is incident on the first surface of the concave lens; and since such a lens makes convergent rays less convergent, the rays emerging from its second surface will converge towards a point F farther distant than P_1,

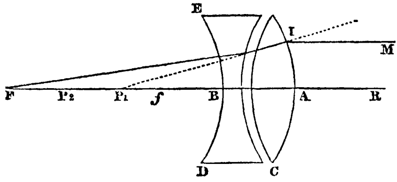

Fig. 41.

and its distance F B from this lens can be computed by the rule given above.

228. A single lens whose focal length is equal to that of a compound lens, is called its *equivalent lens.* The greater the focal length, the less is the convergent power of a convex lens; and on the other hand, the less its focal length, the greater is its convergent power. The power, therefore, of a lens to alter the vergency of a pencil, is inversely as its focal length.

Focal Length of a Compound Lens.

229. If a compound lens is composed of any number of single lenses placed in contact, and of inconsiderable thickness, compared with their focal lengths; "the sum of the reciprocals of the focal lengths of the separate lenses is the reciprocal of the focal length of the compound lens."

230. EXAMPLE.—The focal lengths of three convex lenses are 6, 10, and 12 inches; when placed in contact, determine the focal length of the compound lens.

231. The reciprocals of 6, 10, and 12, are $\frac{1}{6}$, $\frac{1}{10}$, and $\frac{1}{12}$; and the sum of these fractions is $\frac{21}{60}$, the reciprocal of which is $\frac{60}{21}$, or $2\frac{18}{60}$ inches.

232. When any one of the single lenses is concave, its focal length must be considered to be negative in reference to the convex lenses, and its reciprocal must be subtracted from the sum of the reciprocals of the focal lengths of the convex lenses.

233. EXAMPLE.—If the second lens in the preceding example were concave, then the reciprocal $\frac{1}{10}$ would have to be subtracted from the sum of $\frac{1}{6}$ and $\frac{1}{12}$; that is, from $\frac{3}{12}$, or $\frac{1}{4}$. Now the difference of $\frac{1}{4}$ and $\frac{1}{10}$ is $\frac{3}{20}$, and hence the focal length is $\frac{20}{3}$, or $6\frac{2}{3}$ inches.

234. If more than one lens is concave, then of course the sum of the reciprocals of their focal lengths is to be taken from that of the convex lenses; and if the former sum exceeded the latter, it would show that the compound lens would cause the finally emergent rays to converge to a principal focus on the same side as the incident light.

235. The same rule applies to find the focal length of a lens compounded of concave lenses; the principal focus being on the same side as the incident light.

236. The preceding articles show how the principal focal length of a compound lens is found when the simple lenses are in contact—that is, the focal length for incident parallel rays; and by means of this focal length, the geometric focus of such a lens, and for any distance of the radiant point, or for

vergent rays, can be found in exactly the same way as for a single lens. The rule is—"Find the principal focal length of the compound lens; then the reciprocal of the distance of the geometric focus of the finally emergent rays is equal to the excess of the reciprocal of the focal length above the reciprocal of the distance of the radiant point."

237. Example.—The principal focal length of a compound lens is 10 inches, the distance of the radiant point is 24 inches; find the distance of the conjugate focus from the lens.

238. The reciprocals of 10 and 24 are $\frac{1}{10}$ and $\frac{1}{24}$; the difference of these is $\frac{7}{24}$; hence the reciprocal of the required focal length is $\frac{7}{24}$, and this length itself is $\frac{24}{7}$, or $3\frac{3}{7}$ inches.

239. If the distance of the radiant point were equal to the focal distance—that is, if the radiant point were in the principal focus—the emergent rays would be parallel. Were the distance of the radiant point less than the principal focal length, the required focus would be on the same side of the lens as the radiant point—the emergent rays would be divergent, and the focus an imaginary one.

240. It is sometimes necessary, in computing the magnifying powers of optical instruments, to find the focus of refracted rays of a compound lens, when some of the individual lenses are separated by considerable intervals.

241. Thus let A, B be two lenses whose axes coincide, P_1, P_2 being their respective principal foci; then if parallel rays X A, R I are incident on the anterior surface of the lens A,

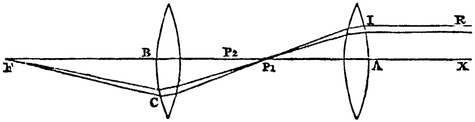

Fig. 42.

they will first unite in P_1 its principal focus, and after refraction through the second lens B, they will unite in the conjugate focus F.

242. First find the focal length A P_1 of the first lens, and B P_2 that of the second lens; then having given B P_1 the distance of the radiant point from the lens B, find the corresponding conjugate focal distance B F.

243. Example.—Let the focal lengths of the first and second lenses be 4 and 3 inches respectively, and the interval between them 10 inches; find the focal length for incident parallel rays.

244. Here A P_1 is 4 inches, B P_2 is 3, and A B 10; hence

P_1 B is the difference between 10 and 4—that is, 6 inches; and the difference of the reciprocals of 6 and 3, or of $\frac{1}{6}$ and $\frac{1}{3}$, is $\frac{1}{6}$, which is therefore the reciprocal of B F; and consequently B F is 6 inches.

245. When two lenses composing a compound lens or eyepiece are separated by a considerable interval, it is sometimes necessary to determine the focal length of an *equivalent single lens*—that is, of a lens that will cause the axis of an incident pencil to cross the axis of the compound lens at the same angle; for it is on this angle that the power depends.

246. Let A and B be the lenses, and R C a ray of a cylindrical pencil incident on A, which, after refraction by the first lens, is incident at D on the second lens B, and after refraction by it, proceeds finally to the focus of refracted rays F′. The power of the compound lens then depends on the angle D F′ B; and if from C a line C F be drawn parallel to D F′, A F would be the focal length of the single lens of *equivalent power*, since it would make the *same* ray R C after refraction cross B X at the same angle.

247. Let P_1 P_2 be the principal foci of the lenses A and B; then the reciprocal of B F′ is the sum of the reciprocals of B P_1 and B P_2 (art. 229). B F′ can thus be found; and it can be deduced by geometrical reasoning, that B P_1 is to A P_1 as B F′ to A F; whence, the first three terms being known, the fourth, A F, can be found.

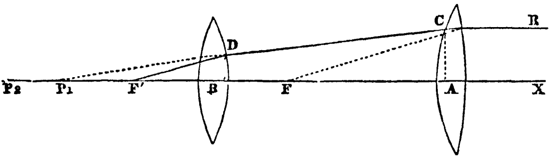

Fig. 43.

248. EXAMPLE.—The focal lengths of two lenses are 3 inches and $\frac{4}{5}$ of an inch, and the interval between them is $2\frac{1}{2}$ inches; find the equivalent lens.

249. Here A P_1 is 3 inches, A B is $2\frac{1}{2}$, and their difference B P_1 is therefore $\frac{1}{2}$ inch. Now the reciprocal of B P_2 is $\frac{5}{4}$, and that of B P_1, or of $\frac{1}{2}$ inch, is 2 inches, and the sum of these reciprocals $\frac{5}{4}$ and 2 inches is $3\frac{1}{4}$ inches, or $\frac{13}{4}$ inches, which is the reciprocal of B F′, and B F′ itself is consequently $\frac{4}{13}$ of an inch. Now B P_1 is to A P_1 as B F′ to A F; or $\frac{1}{2}$ is to 3 as $\frac{4}{13}$ to A F; therefore A F is $1\frac{11}{13}$ of an inch.

250. A single lens, therefore, of this focal length would have the same refractive power as the combination in question.

Aplanatic Lenses, Single and Compound.

251. When lenses have no spherical aberration—that is, when all the rays of the same colour refracted through a lens converge exactly to a single point—it is said to be *aplanatic.*

252. Given a radiant point, an aplanatic lens may be formed thus :—If R be the imaginary radiant point of a convergent pencil, of which A V, B I are two rays incident on the lens M V U, and if its form and position are such that R C is to C V as the sine of incidence to the sine of refraction, all the rays after refraction at the first surface M V U—that is, all the rays within the medium M *u*—will be directed towards a single point F; and if therefore the second surface *m v u* of the lens have this point for its centre, the rays within the medium, being in the direction of the radii of this surface, and therefore perpendicular to it, will proceed without change of direction to the focus F.

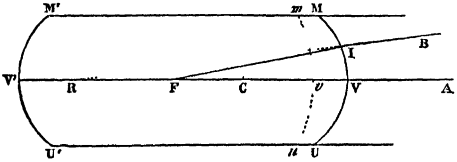

Fig. 44.

253. In like manner, if divergent incident rays have F for their radiant point, they would follow the same path in a reverse direction, and after refraction be divergent from the imaginary focus R.

254. If the lens had for one of its surfaces M V U, and for the other a surface whose centre is R, but situated on the other side of it, or towards it, a divergent pencil from R would, both after the first and second refractions, verge towards F, so that F would be the imaginary focus of the emergent pencil.

255. Lenses with one surface spherical, and the other spheroidal, and lenses with a plane and a hyperboloidal surface, will refract certain pencils without aberration.

256. Thus if an ellipse A B I (fig. 45), whose major axis A B is to its double eccentricity F *f* (the distance between its foci), as the sine of incidence from air to the sine of refraction in a given medium; then it can be proved, from the properties of the ellipse, that the spheroid formed by the revolution of the ellipse about its axis A B, and consisting of the same matter

as that medium, will accurately refract incident parallel rays X B, R I to the farther focus F within the medium.

257. Hence if C B D be a lens contained by the spheroidal surface C I B, and a concave spherical surface C V D, whose centre is F, it is evident that the parallel incident rays X B, R I, when refracted at the first surface, being then directed to F, will not change their direction by refraction at the concave surface, and will therefore converge accurately to F. The lens, therefore, in this case is aplanatic.

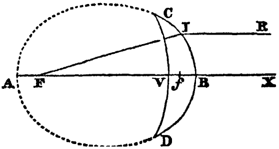

Fig. 45.

258. So if the lens were contained by the spheroidal surface C B D F, and a convex spherical surface beyond it towards X, having F also for its centre, then parallel rays incident on the concave surface C B D would be refracted into a divergent pencil, having F for its virtual focus; and this pencil would pass through the convex spherical surface without change of direction, so that F would still be the focus of emergent rays.

259. When a medium is terminated by a hyperboloidal surface C B D, having its major axis A B to its eccentricity F f as the sine of refraction of the medium to the sine of incidence in air, incident rays in the medium parallel to the axis will be refracted to the external focus f; and if the medium be also limited by a plane surface C V D perpendicular to the axis, the pencil will proceed unaltered in direction to the convex surface C B D, and will therefore form an emergent pencil converging to F.

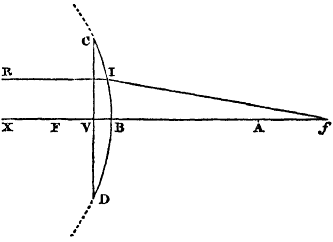

Fig. 46.

260. A lens of glass whose index is $\frac{3}{2}$, that shall have the least possible aberration for parallel rays, must have the curvature of its surfaces of the same kind—that is, both convex or both concave—and the radii of the surfaces as 1 to 6, the more curved side being the anterior surface.

261. If two plano-convex lenses are placed in contact, with both curved surfaces turned towards the light, the aberration is only one-fourth of that of the single equivalent convex lens

formed by placing the two plane surfaces together, although the focal distances in both cases are sensibly the same.

262. If a double convex lens of the respective radii 5·833 and 35, and a meniscus with radii 3·688 and 6·291, or 2·054 and 8·128, are placed in contact, the first being anterior, and the more curved side of the first and the convex side of the second turned towards the light, the compound lens will be entirely free from aberration for parallel rays, whatever be the material it is made of, provided the same material is used for both lenses.

COMPOSITION OF LIGHT.

PRISMATIC COLOURS.

263. The laws of reflexion and refraction hitherto considered refer to *homogeneous* light—that is, light of only one colour; but the rays emitted from most luminous bodies are compounded of light of various colours. The light of the sun, which is white in its natural state, when made to pass through a prism presents an array of seven distinct colours, called *primary*, and also *prismatic* colours; these are *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*. Their *refrangibilities*—that is, the degrees that they are severally refracted under the same circumstances—are different: the violet is most refracted; the red the least; and the refrangibilities of the intermediate colours follow the order of the above enumeration.

264. Let A be the refracting angle of a prism A B C, seen in a cross section, and W I an incident ray of light passing into a dark apartment, through either a very minute circular aperture W in a window-shutter, or (what is better) through a very narrow rectangular slit in a slip of copper fixed in the shutter, its length being parallel to the lateral edges of the prism; then whenever the ray enters the prism at I, its component simple colours, being refracted in different degrees, immediately separate in obedience to their peculiar laws of refraction, and form a divergent pencil, which on emergence continues to be a divergent pencil of different colours, and on being received on a white surface, as a screen of white paste-

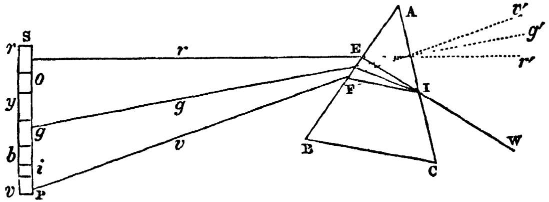

Fig. 47.

board, forms a coloured elongated picture P S, called a *spectrum*, or in this case the *prismatic spectrum*.

265. If the whole length of the spectrum formed by a flint-glass prism is reckoned 360, the lengths occupied by the separate colours are—*v* 109, *i* 470, *b* 48, *g* 46, *y* 27, *o* 27, *r* 56. The light near the middle of the yellow has the greatest intensity; the brightness decreases from this point gradually to the ends of the spectrum, being extremely faint at the violet. The indices of refraction for crown-glass are—*v* 1·547, *i* 1·542, *b* 1·536, *g* 1·533, *y* 1·530, *o* 1·527, and *r* 1·526.

266. It had long been known to painters that the ordinary colours consist of red, yellow, and blue, and their mixtures. The optical hypothesis of three primary or elementary colours was first imagined by Mayer, who produced all the prismatic colours by combinations of red, yellow, and blue. Dr Young assumed red, green, and violet as the primary colours, and showed that the others can be formed by combining these in different proportions. By analysis of the colours of the prismatic spectrum, Sir David Brewster also showed that if the spectrum be considered as composed of three simple spectrums of red, yellow, and blue, in different degrees of intensity at different parts of the spectrum, the result would be exactly similar to the real spectrum. The point of greatest intensity of the simple red spectrum is near the middle of the red space in the common spectrum; the maximum intensity of the yellow spectrum is in the middle of the yellow space; and the maximum for the primary blue spectrum is between the blue and indigo. These three colours, in proper proportions, also constitute a white light; and wherever one of them predominates over the other two, coloured light is produced. On this subject, however, there is an absence of all positive proof, as any colour may be formed by combining others.

267. If the eye were applied at E F, coloured images of the aperture W would be seen at $v' g' r'$; the image in the direction of the violet ray at v' would be violet, that at r' in the direction of the red ray would be red, and so on; so that, in fact, another spectrum would be seen at $v' g' r'$ exactly similar to the first, with the colours in an inverted order.

268. In looking through a prism in this manner at a small white object, a lengthened coloured image of it would be seen; so in looking in the same way at any white ground, as a piece of white paper, a spectral image is formed of every point of it; but these images, by overtopping, blend all the colours together in the exact proportion to produce the impression of white light, excepting at the two edges of the paper that are parallel to the lateral edges of the prism; but, as in

these the extreme image on the side next the refracting angle is not entirely overtopped by the next image within, the most refrangible colour of the extreme image—namely, the violet—remains an outstanding colour. For a similar reason, the extreme image of the other edge of the paper farthest from the refracting angle, is not wholly overtopped by the adjacent images, so that its least refrangible colour remains outstanding from the general white image. The image of the paper is thus white, having these two opposite edges beautifully fringed, one with violet, and the other with red.

269. On the same principle, a dark object on a white ground—as a blot of ink on a sheet of paper—is seen with its borders fringed like a white object; but the colours are reversed—that on the edge nearest the refracting angle being red, and that on the other violet. When the refracting angle of the prism is great, the fringes will be almost entire spectrums.

270. When the spectrum is carefully examined by using a good prism, and a thin beam of light, there are certain lines visible in it, called the *fixed lines of the spectrum.* Most of these lines are dark, but some of them are bright. They lie across the spectrum in a direction perpendicular to its length, or parallel to the boundaries of the different colours, or parallel to the lateral edge of the prism. They were observed first by Dr Wollaston, by applying his eye to the prism in the way mentioned above; but thirty years afterwards, Fraunhofer, by using a telescope instead of the naked eye, counted about 500 of them, and Sir David Brewster has extended the number to about 2000.

271. The most prominent groups of lines lying in the various coloured spaces have received the names B, C, D, E, F, G, H; and the refractive powers of the different colours are now referred to them, thus affording a very precise mode of measuring the indices. The lines have different positions for different media with the same light, and are different for the same medium with different light.

272. If a cylindrical pencil of light after refraction at a prism which renders it a divergent-coloured pencil, is incident on another equal prism, having its lateral edges parallel to those of the former, but its refracting angle turned in a reverse position, and if the light is incident on both at the angle of minimum deviation, the second prism will exactly reverse the effect of the first, and will cause all the rays of different colours to emerge in a cylindric pencil of white light: also the emergent ray will be parallel to the incident ray.

273. Thus if A B C (fig. 48) be the first, and U V W the

second prism, the parallel rays R I, after passing through both prisms, will emerge in the cylindric pencil E M parallel to I R.

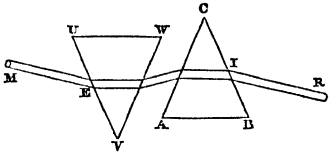

Fig. 48.

274. The refractive powers of different media being different, if a pencil of rays is incident on two prisms of different media at such angles as will make the entire refraction or deviation of the middle or mean ray the same for both, it will be found that the spectra formed by them on equidistant screens are of unequal length, or, in other words, that the colours are more separated by one of the prisms than by the other. This separation of the colours is called *dispersion;* and different media have thus different *dispersive* powers. Not only are the dispersive powers of media different, but the colours are unequally dispersed; that is, the length occupied by a colour does not always bear the same proportion to the whole length of the spectrum. This unproportional dispersion of the colours is called the *irrationality* of the spectrum. The dispersion of any two rays of the spectrum is measured by the angle at the point of emergence, contained by lines drawn from it to the colours in the spectrum.

275. One medium may produce the same amount of dispersion as another with a less refraction. If, therefore, a cylindrical pencil is incident on a prism of one medium at such an angle as to cause a dispersion equal to that produced by another prism with a different refracting angle, and causing of course a different amount of deviation of the mean ray; then the pencil, after refraction at the second prism, when placed as in art. 274, will, on emergence, be composed of parallel rays of different colours; but the emergent will not be parallel to the incident pencil. In the former case, there was no final deviation; in the present case, there is a deviation: consequently it is a case of effective refraction, or a change in the final direction of the pencil without colours.

276. When two media not contained by parallel planes, and causing different degrees of refraction, correct each other's dispersion, they are said to form an *achromatic combination.*

277. Two prisms of different media may therefore be cemented together, so as to form a compound achromatic prism. If a plate-glass prism have a refracting angle of 60°, it will give for its *minimum deviation* an angle of 38°, and a dispersion of 1° 24′; and a prism of flint-glass, with a refract-

ing angle of 35° 34′, and a mean refraction or deviation of 23° 34′, will give exactly the same amount of dispersion; and if a pencil be made to pass through the prisms placed in the reversed position, and so inclined that the mean ray will pass through each of them with a minimum deviation, they will achromatise each other, and at the same time produce a final refraction or deviation of 14° 30′. In this case the extreme rays (red and violet) are dispersed by each at an angle of 42′, but in opposite directions.

278. Although, by this adaptation of the prisms, the extreme emergent rays are made parallel, yet, on account of the irrationality of the spectra of the two prisms, the other rays are not brought exactly to a parallel direction; so that there is still some degree of colouring produced; or the edges of an object seen through the double prism would have coloured fringes, although very minute.

279. When a pencil of white light is incident on a lens, it is evident that since the differently-coloured rays have different indices of refraction, their foci will not coincide. As the violet rays have the greatest refrangibility, their geometric focus will be nearer to a convex lens than the foci of the other colours.

280. Let a cylindrical pencil, of which X V is the axis, and M A, N B two extreme rays, be incident on a lens A B. Supposing there is no spherical aberration, the violet rays would converge to a focus *v*, and the red to another focus *r* farther from the lens, the green to a point *o* in the middle between *v* and *r*, and the other coloured rays to other foci, according to their refrangibilities. The point *v* would thus be of a violet colour, *r* red, and so on. Also, if a piece of card were held at *o*, perpendicularly to the axis *o* V, a circular space on it, of which *o* is the centre, and *c e* the diameter, would be illuminated with differently-coloured rays; the centre being green, and surrounded by rings composed of the other colours.

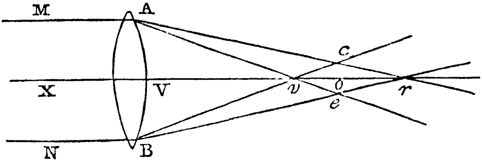

Fig. 49.

281. It has been already mentioned that a single surface or lens might be free of aberration of form for a particular posi-

tion of the radiant point; but this is not the case for chromatic aberration: in other words, though a single surface or a single lens may be *aplanatic* for a particular position of the radiant point, it is impossible for them to be *achromatic*, or free of aberration of colour. But by means of a combination of two or more lenses, an almost perfect freedom from colour can be produced.

282. The longitudinal dispersion of a lens—that is, the distance between the foci of red and violet rays—can be found for incident parallel rays by determining the principal focal distances from the indices belonging to these rays; the difference of these is the required dispersion.

Achromatic Object-Glasses.

283. Let A B, A e B be a concave and convex lens of different kinds of glass; let parallel rays be incident on A B, and let v_1 r_1 be the foci of violet and red rays, after refraction through the first lens; also let v_2 r_2 be their foci after refraction through the second; it is required to determine the conditions under which the foci v_2 and r_2 shall coincide, and consequently all the other intermediate coloured rays, so as to produce white light in one focus, and prevent chromatic dispersion.

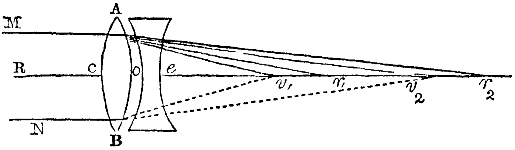

Fig. 50.

284. The principal focal distances $o v_1$, $o r_1$ can be computed; and if the form and refractive powers of the lens are given, when $o v_1$ is found, v_1 is to be considered the radiant point of a convergent pencil incident on the second lens, and consequently the focal distance $o v_2$ after the second refraction is found as already shown; $o r_2$ is to be similarly computed, and the points v_2 r_2 being considered as coinciding, these two focal distances would be equal, and the quantities by which their values are expressed would also be equal. Now these values involve the principal focal distances of the two lenses, and the terms that express their dispersive powers; and from the result of the investigation, this remarkably simple relation is found—"the focal distances of the lenses must be proportional to their dispersive powers."

285. The radii of the two surfaces of each lens are so far arbitrary, that it is required only that the lenses shall have certain focal lengths; a condition that can be satisfied by an indefinite number of forms of the lenses. It is therefore allowable to assume the curvatures of the surfaces in contact to be the same, that they may coincide and be cemented together. Having assumed one surface of each lens, the radii of the other surfaces can be computed.

286. Since the assumption of two of the radii of four surfaces of the two lenses is arbitrary, it is therefore possible to subject them also to the conditions of *aplanatism.*

287. On account of the irrationality of the spectra of different media, it happens that, although by the above method the extreme rays, or the red and violet, are made to unite in one point, some of the coloured rays about the middle of the spectra, as the green, will not be rendered parallel, and will form a small circular greenish image instead of a point; and therefore it is preferable to unite two other colours instead of the extremes, and these ought to be the most strongly illuminating colours, such as the red and yellow or green; and though the violet will thus become an outstanding colour, yet its comparative intensity is so small as scarcely to produce a sensible effect.

288. The outstanding colour, called the *secondary* spectrum, could also be corrected—that is, united with the other two—by using three lenses; but there would be some colour still outstanding, forming a *tertiary* spectrum, though much fainter than the secondary one; so four lenses would form a still more perfect achromatism: but each additional lens causes the loss of so much light.

289. The prismatic decomposition of light is exemplified in the phenomenon of the *rainbow*, which makes its appearance when the sun is shining, and when in some opposite quarter of the heavens rain is falling at the same time. The sun's rays, on entering the rain-drops, are refracted and resolved into colours; a certain number of the coloured rays pass out on the other side of each drop; but of the rest some are turned back by total reflection, and made to pass out in front in a state of decomposition. Of a great many drops thus sending out coloured rays, there will be a band whose rays will reach the eye of a spectator, but only one colour for each drop; and one set of drops will supply a blue ray, another set an orange, a third a yellow, and so on till the spectrum is completed.

290. There are often two bows visible—an inner and brighter, and an outer and fainter bow. The order of the colours is

inverted in the outer bow. It is formed by the rays that issue after two reflexions within the drops.

291. It is geometrically impossible for a ray once reflected by total reflexion, within a *spherical* drop, ever to be emitted from the drop; consequently with perfectly round drops a rainbow is impossible. We must, therefore, assume that the rain-drops are not of an exact round figure, but are flattened by their passage through the air. The spherical form once lost, the emergence of rays after one or two reflexions becomes practicable.

OPTICAL INSTRUMENTS.

MULTIPLYING AND MAGNIFYING GLASSES.

292. If a piece of glass is formed with a number of plane sides or faces, and if the eye is directed to one of them, a number of images will be seen. Thus if A D B is such a *multiplying* glass, an eye at F will see three images of a ball G—namely, the image G formed by the direct rays G D F, and H by the obliquely-refracted pencil H C *u* F; inasmuch as an object always appears to lie in the direction of the emergent pencil, as H *u;* so the image I is seen in the direction of the ray I *v*.

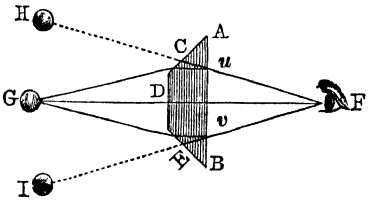

Fig. 51.

293. If a convex lens, with a focal length less than the distance of distinct vision, is placed between the eye and an object situated in the focus of the lens, the rays of each pencil proceeding from any point in the object will emerge parallel, and an image of it will be seen distinct and *magnified.* "The size of the image will be to that of the object as the distance of distinct vision to the focal length of the lens."

294. The cause of the parallelism of the emergent rays and of the enlargement of the image may be thus explained:—Let E (fig. 52) be the eye, and *m n* the diameter of its pupil, and R W a small object placed at the least distance of distinct vision. When the lens A B is placed so that R W is in its focus, the conical pencil of rays proceeding from any point R, having the first surface of the lens for its base, will, after passing through the lens, emerge in a cylindrical pencil parallel to the central ray R C P, or the axis of the incident conical pencil; but only a small portion of the refracted pencil—namely, the small pencil A *m n a*—will fall on the pupil and enter the eye, and form on the retina an image of the point R. Now this point will be seen in the direction of the point *m* A, or at R′;

in like manner, the other extremity W will be seen at W′, and the points intermediate to R and W will have images intermediate between R′ and W′. Thus the whole image will exceed the object in the proportion of R′ W′ to R W; but these lines are to one another as E M to C M, or as the distance of distinct vision to the focal length of the lens.

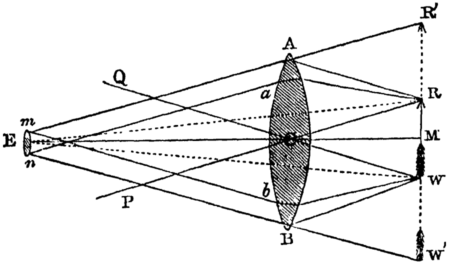

Fig. 52.

295. The visual angle R E W would be to the angle R′ E W′ nearly as R W to R′ W′; so that the visual angle is enlarged in the ratio of the distance of distinct vision to the focal length of the lens.

296. A convex lens, from the property it possesses of enlarging the apparent size of objects, is called a *magnifying glass* or a *single microscope.*

297. An object may be magnified on a different principle, by using a lens whose focal length exceeds the distance of distinct vision. It is evident from the preceding article, that when the focal length is equal to this distance, the image is of the same size as the object. Let now the focal length exceed this distance, and let an object A C be placed beyond F, the principal focus; it will form an image *x b z*, which may be seen as if it were a real object, by an eye placed at the distance of distinct vision; for rays proceed from points in the image just as if it were a real object, only not in all directions. The image of the point A will be at *z*, of B

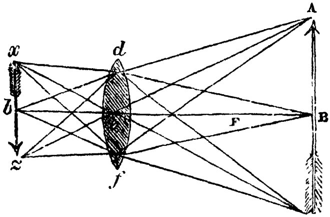

Fig. 53.

at *b*, and of C at *a*. These conjugate foci are computed by the rules formerly laid down. The image is necessarily *inverted*. If the object A C is very distant compared with the focal length of the lens, then the distance of the image from the lens will be very nearly its focal length, and the magnifying power will be determined thus :—" As the least distance of distinct vision is to the focal length of the lens, so is the apparent size of the object seen by the naked eye to its apparent size seen by means of the lens."

298. The proof of this theorem is as follows :—M N is the object, A B the lens, *m n* the image, *e* the pupil of the eye, and

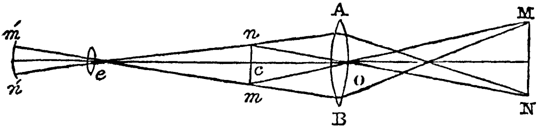

Fig. 54.

m′ n′ the image on the retina of the eye. The object M N being distant, the image *m n* will be nearly in the principal focus of the lens A B, so that O*c* is its focal length. The apparent magnitude of the object, if seen by an eye placed at O, would be measured by the angle M O N ; and as O *e*, the sum of the distance of distinct vision *e c*, and *c* O, is small compared with O M, the distance of the object, the angle M O N may be considered as the visual angle of the object seen by the unaided eye. Now the angle *n e m* formed at *e* by the crossing rays *n e*, *m e*, is the visual angle of the image *m n;* hence the apparent size of the object compared with that of its image is as those visual angles—that is, as the angle M O N or *m* O *n* to *m e n*. But these angles are as their halves—namely, the angles *c* O *n*, *c e n*, which, from the properties of a triangle, are as the opposite sides *n e* and *n* O, or very nearly as *c e* and *c* O; but *c e* is the distance of distinct vision, and *c* O the focal length of the lens; hence the theorem is as stated above.

299. Example.—Let *c e* be 8 inches, and *c* O 32 inches; then the apparent size is increased in the ratio of 8 to 32, or 1 to 4; or the magnifying power is 4.

300. The lens thus used forms what may be called a simple telescope ; but in the common telescope, the image *m n*, instead of being viewed directly by the eye, is observed through a lens or combination of lenses, called an eye-piece, and A B is termed the *object-glass*. When a single lens is used, the equiconvex is best. The lenses of eye-pieces are usually of the

same kind of glass, the correction for colour being effected in a different manner from that of an object-glass.

EYE-PIECES.

301. The construction of achromatic eye-pieces is of great importance; but the principles of their construction are more complicated than in the case of object-glasses; for in these the axes of all the incident pencils from the object pass through the centre of the lens; whereas the axes of pencils incident on an eye-glass do not pass through its centre. When, therefore, a single lens is used for the eye-glass, a thin pencil proceeding from a point in the image formed by the object-glass, will, on refraction, form a narrow spectral line lying in the direction of a radius of the field of view, or of the corresponding radius of the circle that bounds the lens. Also the rays emergent from the eye-glass will not all have the same degree of vergency; so that only a portion of the field will be seen with any tolerable distinctness. In the third place, the eye-piece distorts the object; causing, for example, the sides of a square to appear curved.

302. These three defects of a single eye-glass are corrected to some extent by a combination of two or more lenses, so as to form what are termed *eye-pieces.*

303. The *achromatic* eye-piece consists of two lenses F D, E Y; the first being called the *field-glass,* because without it the field of view would be less, or fewer rays would fall on the second lens, which is next the eye, and hence called the *eye-glass.* If I F is a convergent pencil from I, and nearly parallel to the axis of the eye-piece, after refraction at F the red ray will be directed to r_1, and the violet to v_1; but this dispersion can be corrected by means of the eye-lens E Y, which will make the rays emerge parallel, or in the directions E r, E v.

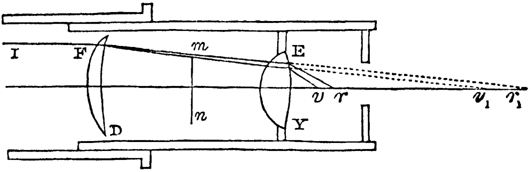

Fig. 55.

304. The arrangement requisite for achromatism is, that the

distance between the lenses shall be half the sum of their focal lengths. In a particular construction of this eye-piece, called that of Hüygens, its inventor, the focal distances of the first and second lenses are as 3 to 1, or their distance is 2 on the same scale.

305. The convexity of the image will be best corrected by this eye-piece when the field-glass is a meniscus, as shown in the figure, having its radii as 11 to 4; and the eye-glass a lens, with its radii as 1 to 6. The focal length of the combined lens may be found by the following rule: "divide twice the product of the focal lengths by their sum."

306. This eye-piece is also called the *negative eye-piece.* It is to be observed that the convergent rays incident on F D are brought to foci between the lenses, and there form an image *m n* which is indistinct and coloured.

307. *Ramsden's eye-piece,* called also the *positive* or *micrometer eye-piece,* is composed of two lenses likewise, but the first or field-glass has the image that is formed by the object-glass before it, and in its focus. This eye-piece is chiefly used for the purpose of giving a distinct image of the whole of a system of parallel wires placed at *m n,* the focus of the object-glass. It consists of a plano-convex and a convexo-plane lens; that is, of two plano-convex lenses with their curved sides turned towards each other. The focal lengths of the lenses are equal, and they are placed at a distance from each other equal to about two-thirds of this focal length. This eye-piece is not perfectly achromatic; and though in this respect it could be improved by increasing the distance between the lenses, a greater disadvantage would be introduced.

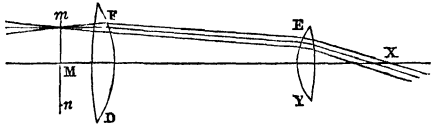

Fig. 56.

308. In the eye-pieces now described, the object appears inverted; hence they are adapted only for telescopes used in astronomical observations, in which the inversion of the image is of no consequence; but for terrestrial objects a more complex eye-piece, consisting of four lenses, is used to produce an erect image, hence called the *erecting eye-piece.*

309. The most approved form of the erecting eye-piece is this: the first, third, and fourth lenses F, C, and E (fig. 57) are double convex, and the radii of their surfaces are respectively for F 27 and 1, for C 1 and 21, for E 1 and 24; the radius first given for each lens being that of its first surface, or the

surface turned towards the light; the radii for the second lens B, which is a meniscus with its concave surface first, are 9 and 4. The three convex lenses are nearly plano-convex.

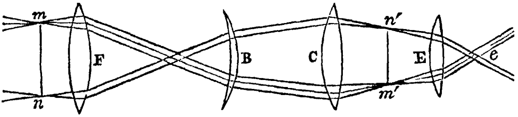

Fig. 57.

These lenses may be of any transparent medium, provided it be the same in all. The focal lengths, beginning with the first, F, are 3, 4, 4 and 3; and the distances between them in order, beginning with F B, are 4, 6, and 5·2 on the same scale. The power of the equivalent lens is nearly the same as that of the first or fourth lens; but more accurately, it will be found on calculation to have a focal length about one-fourth less, or nearly $2\frac{3}{11}$.

310. An inverted image *m n* of a distant object M N, being formed in the focus of the object-glass, the rays proceeding from every point in it, as from an object, are again brought to a focus between the third and fourth lenses, and form an erect image *m′ n′* of the object which is seen by the eye at *e*.

311. The third lens, C, is called the field-glass, and the fourth, E, the eye-glass; these two are usually placed in one tube, and the first and second in another. If the distance between the second and third lenses is increased, the power of the telescope is also increased, though at the expense of the field of view.

312. An eye-piece is sometimes used, consisting of three lenses, which are generally of the same material, of equal focal lengths and equi-convex. The consecutive intervals between any two of them are equal to the sum of their focal lengths. This eye-piece is neither aplanatic nor achromatic, but it affords a greater field, and admits of higher powers with a simple object-glass than the foregoing, and it is also an erecting eye-piece; it may be called the *triple erecting eye-piece*. It is tolerably well adapted for terrestrial telescopes of moderate power, as from 4 to 10; but for higher powers it would be indistinct, unless the object-glass had a very great focal length.

313. This eye-piece is represented in the figure. The object-glass A B (fig. 58) of a telescope forms in its focus an inverted image *m n* of an object, and the eye-piece is placed so that the image *m n* shall be in the focus of the first lens C D; the

rays of each pencil then emerge parallel till they reach the lens E F, when they converge to its principal focus, and there form another image *m′ n′* in the focus of the third lens, or eye-glass G H, from which the rays emerge parallel, and in a proper state to produce vision.

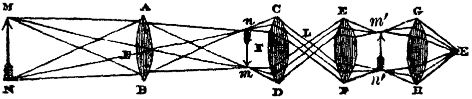

Fig. 58.

SOLAR MICROSCOPE AND MAGIC LANTERN.

314. In the solar microscope and the magic lantern, a magnified image of a small object is formed on a wall or screen, to be viewed by a number of persons at the same time. It is therefore necessary to produce a flat image. The best forms and arrangement of the lenses for producing this effect are, that there should be two lenses of equal focal lengths placed at a distance from each other equal to $\frac{2}{3}$ of that length; that the one next the object should be a plano-convex, and that next the screen a meniscus, whose radii are as 1 to 15, with their convex sides turned towards each other—a construction similar to that of the positive eye-piece.

315. Thus in the magic lantern, which is placed in a dark chamber, *m n* is the object; O I the lenses by which the image M N is produced on a screen; F the flame of a lamp, to illuminate the object *m n;* T E a lantern or box, and C a chimney; L a lens to concentrate light on the whole surface of the

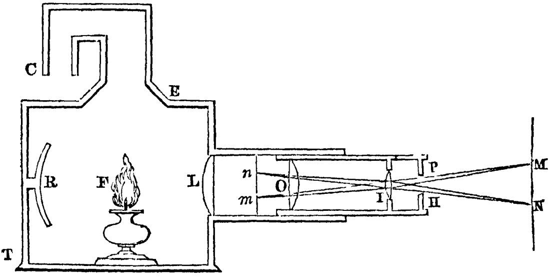

Fig. 59.

object, which is painted with transparent colours on glass sliders, the rest of the glass being opaque; R is a concave mirror, to reflect additional light on the object; and P H is a diaphragm, to intercept the extraneous rays, and thereby produce a more distinct image.

316. If the distance of the screen is altered, so must the position of the lenses; and the farther the screen, the larger is the image; when grotesque figures, dissolving views, demons, dragons, and the like, are exhibited, they are called *phantasmagoria.*

317. When, instead of artificial light, the sun is reflected on the lens L in the direction of its axis, and when minute natural objects are used, the instrument is a *solar microscope,* the lantern T E C being dispensed with.

318. The *camera obscura* (which means a dark chamber) is an instrument for producing a distinct image of a landscape by receiving it on a white ground, as a sheet of paper in the interior of a dark box.

319. M R is a plane mirror, L a lens, *m c r* a white concave surface, on which the image of the landscape is formed, D P a diaphragm, and O an opening in the side of the box, large enough to let in the head of the observer; there is sometimes another opening lower down to admit the arm, so that a person may be able to trace the picture on a sheet of paper. The lens is plano-convex, with its plane side directed to the incident rays; the diaphragm is about ⅓ the focal length of the lens above it; the radius of curvature of the concave ground *m c r* must be 1⅓ times the focal length. The concave surface ought to be movable up and down, to correspond to different distances of the picture.

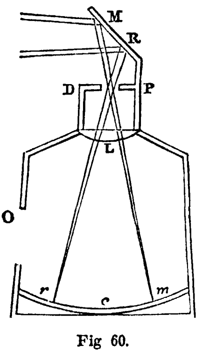

Fig 60.

320. There is a certain distance from any eye where an object can be seen distinctly without effort, which is called the distance of *indolent* or *passive vision,* and beyond this distance it is impossible for the eye to see distinctly. Within this limit, however, the eye, with some degree of effort, can see objects distinctly, if they are not nearer than a certain distance, varying from 5 to 10 inches, which is called the *least distance of distinct vision.* The compass of distinct vision comprises an extensive range between these limits,

which may be called the *superior* and *inferior limits of vision.* When the distance of an object is considerable, the rays from it enter the eye nearly parallel; so that the eye, in its passive state, is adapted to parallel rays; and consequently optical instruments are so constructed that the finally emergent rays belonging to any one original pencil emitted from a point of the object may be parallel. The axes of the *different pencils,* however, are not parallel; for we have seen that the inclination of the axes of the extreme pencils determines the magnifying power.

TELESCOPES.

321. Optical instruments for observing distant objects are termed *telescopes,* from two Greek words, meaning *far,* and *to see.* The simplest form of the telescope is a single convex *lens;* either double convex, plano-convex, or meniscus, with a focal length greater than the distance of distinct vision.

322. When the object is at a great distance, compared with the focal length of the lens, it was found (art. 297) that the magnifying power is measured by the ratio between this focal length and the distance of distinct vision. Taking this last distance as 7 inches, and supposing the focal length of the lens to be 35 inches, the magnifying power will be the ratio of 35 to 7, or 5 to 1; that is, it will be expressed by the number 5, implying that the apparent magnitude of the object seen by means of the lens is 5 times greater than its apparent magnitude seen by the naked eye.

323. If, however, the object is not very distant, the magnifying power is estimated differently; for then the conjugate focal length om is greater than the principal focal length. But still the ratio of oc to ce will be that of the apparent magnitude of the object seen with the lens, to that seen without the lens, if the eye were placed where the lens is.

324. It is evident that if the image mn (fig. to art. 297) were formed by means of a concave *mirror* of greater focal length than the least distance of distinct vision, the object would be seen magnified, and the power could be computed exactly in the same manner. The mirror, however, would require to be slightly inclined, in order that the head of the observer may not intercept the incident rays.

325. Instead of using a single lens or mirror in the construction of a telescope, a combination of lenses, or of mirrors and lenses, are used; the first are called *refracting,* and the second *reflecting telescopes.* In a refracting telescope, the lens nearest to the object is called the *object-glass,* and the combination of lenses next the eye the *eye-piece;* or if, as sometimes

happens, there be only one lens used for an eye-piece, it is called simply the *eye-glass*. In a reflecting telescope, the larger mirror that receives the incident rays is called the *object-mirror;* and another smaller mirror facing it, and near its principal focus, is the *small mirror;* an eye-piece or single eye-glass is also used next the eye.

Refracting Telescopes.

326. A telescope having a single convex lens for its eye-piece is called the *astronomical* telescope; it consists, therefore, of only two convex lenses—the object-glass and eye-glass, the focal length of the latter being less than that of the former.

327. Let B C be the object-glass, and *i v* the eye-piece; let *a* B, *b o*, *d* C be three rays of a pencil proceeding from a point in the upper part M of a distant object M N, and *r B*, *s o*, *t* C rays of another pencil proceeding from a lower point N; then if the object be at a considerable distance, these pencils will be very nearly cylindrical; therefore the upper pencil, after refraction at the object-glass, will converge towards the principal focus *m*, situated on the central ray *b o m*, and the rays of the lower pencil to the focus *n*, on the central pencil *s o n*, and the intermediate pencils from other points in a vertical line of the object, will meet in foci between *m* and *n*, so that an image *m n* is thus formed in the focus. If now the eye-glass *i v* is so placed, that the image *m n* may be in its principal focus, the rays of the pencil from M, diverging from *m*, will, after refraction at the eye-glass, emerge parallel to the central line *m e*, and the rays of the pencil diverging from *n*, will emerge parallel to *n e*, and thus all the rays of any one emergent pencil will be parallel, and will therefore form a distinct image of the point of the object from which the pencil originally emanated on the retina of an eye situated at *c;* but the object will appear to be inverted.

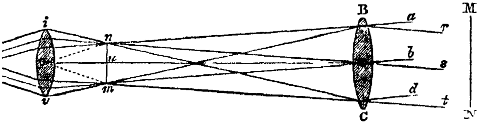

Fig. 61.

328. The magnifying power will be determined by the ratio of the apparent magnitudes of the image and of the object when the latter is seen by the naked eye. The apparent magnitude of the object seen by the unaided eye situated at the object-glass, would be measured by the angle *b o s*, contained

by the central rays from the upper and lower ends of the object M N; and this angle is the same as *n o e*. Again, the apparent magnitude of the image is determined by the inclination *e* of the axes of the pencils from *m* and *n*; but this angle is equal to *m e n*; and the two angles *m o n*, *m e n* are proportional to their halves, the angles *n o u*, *m e u*; and these angles being small, are very nearly proportional to the sides *n e*, *n o* of the triangle *n e o*, or to the lines *e u* and *o u*, which are the focal lengths of the eye and object-glasses. Hence "the magnifying power is the ratio of the focal length of the object-glass to that of the eye-glass." Thus if the focal lengths are 20 and $1\frac{1}{4}$ inches, the magnifying power would be 20 divided by $1\frac{1}{4}$, or 16, or the object is magnified 16 times.

Galilean Telescope.

329. When the eye-glass of a refracting telescope is a concave lens, it is called the *Galilean telescope*, from its inventor Galileo. In it there would be an image *m n* formed in the focus of the object-glass B C, exactly as in the case of the astronomical telescope, if the eye-glass *i v* did not intercept the rays incident on it, and refract them in cylindrical pencils, as shown in the figure. In order that the rays of each incident pencil may thus emerge parallel from the concave eye-glass, it is merely necessary that its distance *e u* from the virtual image *m n* be equal to the focal length of the lens. It can be shown that, as in the astronomical telescope, the magnifying power is the ratio of the focal lengths *o u*, *e u* of the object and eye-glass. The object will appear erect. The common opera-glass is a Galilean telescope. It cannot be used with high powers.

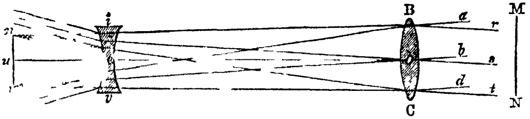

Fig. 62.

Terrestrial Telescope.

330. The telescope that can be used with the highest powers for terrestrial objects, is one with an achromatic object-glass and the erecting eye-piece formerly described; the first glass in the eye-piece being so placed that, like the eye-glass in the astronomical telescope, the image *m n* (fig. to art. 327) may be in its principal focus. With this telescope, magnifying powers

to the extent of 60 or 80 may be obtained with a tolerably large field and a distinct view. This may therefore be properly called the *terrestrial telescope.* Its magnifying power is found by dividing the focal length of the object-glass by that of the single lens equivalent to the eye-piece. The magnifying power may be increased by enlarging the distance between the second and third lenses; that is, by drawing out the tube containing the field and eye-glasses. The triple erecting eye-piece may also be used like the above, only the image *m n* must be exactly in the focus of the first lens. But the proper position of the eye-piece is easily found by observation, being that which affords the most distinct vision.

331. In any telescope, if the eye-glass and other lenses in an eye-piece are large enough to permit all the rays entering the object-glass to pass through them, the ratio of the breadth of the object-glass to that of the emergent pencil expresses the magnifying power. Also if the emergent pencil is just broad enough to fill the pupil of the eye, the brightness of the image will be the same as when the object is observed by the naked vision, excepting that with the telescope the brightness will be weakened by the passage of the light through the several lenses.

Reflecting Telescopes.

332. Since reflecting telescopes are necessarily achromatic, mirrors of large diameters may be constructed which will, with a moderate focal length, allow an eye-glass of small focal distance to be used, and therefore yield a great magnifying power.

333. One convenient form of the reflecting telescope is that proposed by Gregory; hence called the *Gregorian telescope.*

334. T is the tube, and A B the object to be represented. At the end opposite from the object there is a small tube *t t.*

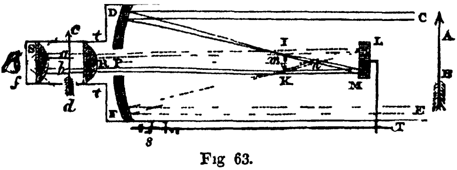

Fig 63.

At the main end of the wide tube there is a concave mirror D F, with a hole in the middle at P. The principal focus of this mirror is at I K; here the image *m* is inverted, and the rays, crossing each other at *n*, go on to the small reflector L. From this they are reflected in parallel lines through the hole P. At P they enter the plano-convex lens R, which causes them to converge at *a b;* but here the image requires to be magnified, which is done by means of the plano-convex lens S; in other words, the object is seen under the angle *c f d.* In order to accommodate focal distances, the small mirror L can be removed to a greater distance, or brought nearer, by the rods and screws communicating from *s*.

335. This form of the instrument is preferred, because it affords an erect image of the object. The rule for finding the magnifying power is this:—"Multiply the sum of the focal distances of the two mirrors by that of the object-mirror; find next the product of the focal length of the small mirror by that of the lens equivalent to the eye-piece; then divide the first product by the second, and the quotient is the magnifying power."

336. EXAMPLE.—If the focal lengths of the mirrors are 20 and 2½ inches, and that of the lens equivalent to the eye-piece 1½; what is the magnifying power?

337. The sum of 20 and 2½ is 22½, and this multiplied by 20 gives 450; again 2½ into 1½ is $\frac{15}{4}$; and 450 divided by $\frac{15}{4}$ gives 120 for the power.

338. *Cassegrain's telescope* differs in construction from Gregory's only in having the small mirror convex instead of concave. The magnifying power is estimated in the same way as in Gregory's; but instead of the sum of the focal lengths of the mirrors, the difference must be taken. The convex mirror corrects in some measure the spherical aberration of the object-mirror. In Gregory's, this mirror ought to be nearly hyperbolic, and in Cassegrain's nearly parabolic; the same mirror does not answer equally for both constructions. Cassegrain's inverts the object. The small speculum is placed nearer the object-mirror than the image in its focus, and this telescope is therefore shorter than Gregory's.

339. The *Newtonian reflector* differs from Cassegrain's in having, instead of the convex speculum, a small plane one placed at an inclination of half a right angle to the axis, so as to reflect the rays out at a round opening in the side of the tube; and there the image is formed and observed by an eye-glass. This small reflector is placed at a distance from the principal focus of the object-mirror, equal to half the diameter of the tube. The only effect of this mirror is to divert the rays in a new direction; it has no influence on the magnifying power. The power of the telescope is the same as if the eye-glass were placed with its axis coinciding with the axis of the

tube, nearer the open end of the tube than the image I K, and having this image in its focus, and viewed by an observer with his back turned to the object; but by this method of observation, so many rays would be intercepted by the observer's head, that unless the object-mirror were very large, a great loss of light would be the consequence. With large mirrors, however, a little inclined, so as to form an image near the side of the tube A D at its open end, this is one of the best methods of observation, and it prevents the loss of light caused by a second reflexion. A reflecting telescope of this construction is called *Herschel's telescope,* in which M is the mirror sending the image to *a* at the edge of the tube's mouth, where it is viewed by the eye-piece E without bringing the observer's head between the object viewed and the mirror.

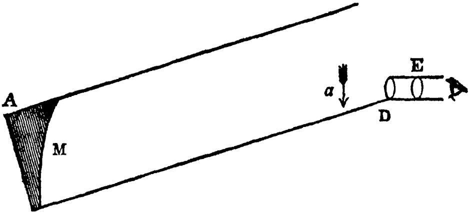

Fig. 64.

MICROSCOPES.

340. When very small objects are to be minutely examined, they require to be greatly magnified. The instrument employed for this purpose is called a *microscope,* from two Greek words, meaning *small,* and *to see.* A single microscope, as stated in art. 293, is a single convex lens, and in using it the object is placed in its focus. If the least distance of distinct vision (from 6 to 10 inches) be called the *visual distance,* it was found that the magnifying power of a single microscope is the ratio of the visual distance to the focal length of the lens.

341. When the object is placed a little farther from the object-glass than its principal focus, an image of it will be formed at a considerable distance behind the lens, much larger than the object; and if this image be viewed with an eye-glass, so placed that the image shall be in its principal focus, a distinct enlarged image of the object will be seen exactly as in the case of a telescope.

342. Let O (fig. 65) be the object-glass, and *a* the eye-glass, M N the object a little farther distant than the principal focus

of O, and *m n* the image; then if *a* is so placed that *m n* is in its principal focus, the emergent pencils will each consist of parallel rays crossing the axis at E, and the apparent size of the object will be measured by the visual angle at E, or its equal *m a n* at *a;* but the visual angle at O is M O N, or its equal *m* O *n;* it appears, therefore, that the visual angle of the object seen from O is increased by the instrument in the ratio of the angles *m a n*, *m* O *n*, or of their halves *n a v*, *n* O *v*, which are as the lines *n* O, *n a*, or *v* O and *v a* nearly; that is, as the distance of the image from the object-glass to the focal length of the eye-glass. But the entire magnifying power is several times greater than this; for in viewing it with the naked eye, the image M N must be held at the visual distance —say 6 inches; whereas O M is only the focal distance of the object-glass: hence the visual angle, when the object is seen by the naked eye, is to the visual angle M O N as the focal length O M to 6; therefore on account of the object being so near the object-glass, the visual angle is increased in the ratio of 6 to the focal length of O; and the visual angle being again increased in the ratio of O *v*, the distance of the image from O, to *a v* the focal length of the eye-glass, the rule for finding the magnifying power is this:—"Multiply the conjugate focal length of the object-glass—that is, the distance of the image from it—by the visual distance; and multiply the focal distances of the object and eye-glasses together; divide the former product by the latter, and the quotient is the magnifying power."

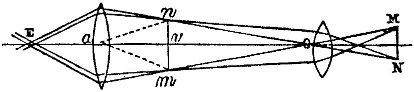

Fig. 65.

343. EXAMPLE.—Let the focal length of the object-glass be $\frac{1}{5}$ inch, the distance of the image from it 3 inches, the focal length of the eye-glass $\frac{1}{2}$ inch, and the visual distance 10 inches; then the product of 3 and 10 is 30, which, divided by the product of $\frac{1}{5}$ and $\frac{1}{2}$, or $\frac{1}{10}$, gives 300 for the magnifying power. The power of the object-glass alone is 10 divided by $\frac{1}{5}$ or 50.

344. When the object-glass is achromatic, and more especially when it is aplanatic, the image is much more distinct. An object-glass of a spherical form has its effect improved by contracting its aperture, and confining it to a small central space.

345. When a compound eye-piece is used, the image is more distinct, but the computation of its magnifying power is more complicated.

THE EYE AND VISION.

STRUCTURE OF THE EYE.

346. The eye, by whose instrumentality we receive a principal class of impressions of the external world, is in part an optical instrument, acting according to the laws explained above with reference to the refraction of light and the operation of lenses. It consists of a ball or globe, not perfectly round, but bulging in front as if a segment of a sphere were cut off, and a portion of a smaller sphere substituted instead. The eyeball is composed of several coats or coverings, which enclose masses of transparent substance called *humours*. Its movements are effected by an apparatus of muscles, and provision is made for holding it in its place in the socket while these movements are permitted.

347. The outermost coat of the eye is a thin transparent membrane covering only the front or visible portion of the ball, and reflected on it from the interior of the eyelids, of which it is the lining membrane. It is called the *conjunctiva.* Over the clear and bulging portion of the eye it is perfectly transparent, and adheres close to the surface; on the parts surrounding the clear portion it is less transparent, and contains a few straggling blood-vessels, which are seen as red streaks on the white of the eye.

348. The main covering of the eyeball is the *sclerotic* coat, which is the outer substance, enclosing all the rest, and serving by its strength and firmness to keep up the rigid form of the eye against every kind of pressure from without, being, as it were, the shell or case of the instrument. The white of the eye is an exposed portion of it. It encloses the ball all round excepting the front portion, which is transparent and bulging, and an aperture behind for receiving the optic nerve. It is composed of interlacing fibres sufficiently strong and dense to produce its unyielding character; it is thickest behind, and in the fore part it approaches to a thin edge, and terminates where the transparency of the eye commences.

349. The transparent bulge which completes the globe and joins on where the sclerotic ceases is termed the *cornea*, or horny coat. It occupies about one-fifth of the whole surface

of the eye, and differs from the sclerotic in being perfectly transparent, while it is of a strong and unyielding structure. The two together complete the encasement of the eye, and no other portion is employed for the mere purpose of maintaining its form and rigidity.

350. Close to the inner wall of the sclerotic coat lie two other membranous expansions, likewise termed coats, but of totally different nature and properties. Next the sclerotic is the *choroid* coat, which is a membrane of a black or deep-brown colour lining the whole of the chamber up to the union of the sclerotic with the cornea, and then extending inwards, so as to form a peculiar ring stretching across the eye. It is also pierced behind by the optic nerve.

351. The choroid coat is an extremely vascular structure—that is, it is composed of a dense mass of blood-vessels which lie in two layers, the outermost of the two being the veins, and the other the arteries. Inside of these two vascular expansions is the layer containing the black pigment which gives the coat its colour, and which it is the object of the numerous blood-vessels to supply. The pigment is enclosed in the cells of a membrane, and these cells are packed very closely together, and are about the thousandth part of an inch in diameter. Each cell has a transparent point in its centre surrounded by a dark margin.

352. Within the choroid, and lining its surface, is the *retina*, which is a nervous expansion branching out from the optic nerve, and covering the interior chamber of the eye with a fine *transparent* network as far as the angle where the choroid bends inwards to form the circular ring above-mentioned. It is a very delicate membrane, of almost a pulpy nature, and but loosely attached, although lying close, to the blackened surface of the choroid. Directly in the back of the eye, and in a line with the axis of the eyeball, is a round yellow spot, and in the centre of this spot is a minute hole called the *foramen* of Sœmerring; it appears to be formed by a deficiency in the nervous substance of the retina at that point. About a fifth of an inch inward from the yellow spot is a flattened circular papilla corresponding with the place where the optic nerve pierces the choroid coat, and consequently where the coat is deficient.

353. The retina is a compound membrane consisting of three distinct layers, only one of these, the middle layer, being made up of purely nervous matter. The outer layer in contact with the choroid, termed the *membrane of Jacob*, is made up of small columns or rods standing perpendicular to the surface, and each sharpened to a point at their outer

extremities. The columns are of two different kinds, one being smaller and more numerous than the other. The small rods are solid six-sided bodies grouped round the larger, which are the shorter of the two, and cleft at the point where they touch the choroid. Each one of the pigment cells of the choroid (of which there are about a million to the inch) receives as many as six or eight of the larger cleft twin cones, with the smaller single rods grouped round them; consequently the diameter of the smaller bodies must be only a fraction of the thousandth part of an inch.

354. The middle layer of the retina is the proper nervous portion. It is made up of radiating nervous fibres proceeding from the optic nerve, and spreading over the inner chamber of the eye. The fibres become more slender and more distant as they approach towards their termination in front. On each side of the fibrous expansion is a layer of nerve cells, or of the peculiar nervous substance composing the ganglia or nervous centres of the body, and occurring generally at the terminations of the nerves of special sense. The inner ends of the rods that make up the membrane of Jacob are therefore in contact, not with nervous fibres, but with nerve cells.

355. The innermost of the three films of the retina is the vascular layer, or the network of arteries and veins required for supplying blood to the nervous portion; a necessity occurring everywhere in the system in proportion to the activity of the parts.

356. Before pointing out the different bodies that make up the bulk of the eye, and enable it to act as an optic lens, we must call attention to several other substances of a membranous character lying under the cornea near the junction with the sclerotic coat. The first of these is a narrow circular band of a grayish-white colour close behind the junction above-named. The foremost margin, the thicker of the two, gives attachment to the circular curtain called the *iris*. The thinner and posterior margin is blended with the choroid coat, which here prolongs itself inward in a series of radiated folds, called the *ciliary processes.* The band or ligament thus giving the twofold attachment to the iris and the choroid is called the *ciliary ligament.* The ciliary processes lie behind the iris, and as they extend but a little way inwards, making a black wrinkled narrow rim, they are completely concealed from external view.

357. The *iris* is the coloured membrane with a black hole in the centre, which we see in the front of the eye, being coextensive with the transparent cornea. Its outer edge is attached to the ciliary ligament, and the inner border corre-

sponds to the aperture of the *pupil* of the eye, through which the blackness of the choroid coat is apparent. On the anterior surface of the iris radiating lines are seen, being differently coloured in different individuals. The posterior surface of the iris proper is colourless, but it is lined with a layer of black pigment similar to the inner layer of the choroid. In structure it is made up of two classes of fibres—one radiating, the other circular. The radiating fibres are most conspicuous at the outer margin; the circular fibres are best seen near the inner margin and behind. These fibres are of a muscular character, and by their contractions serve to alter the size of the pupil. The radiating fibres when in action enlarge the hole, and the circular fibres contract it, the purpose being to govern the quantity of light admitted into the eye.

358. The substance of the eye is made up of three humours or transparent masses extending from front to back: the foremost is called the *aqueous humour;* the middle the *crystalline lens;* and the backmost the *vitreous humour.*

359. The *aqueous* or watery humour is a clear watery liquid lying under the cornea in front, and bounded behind by the ring of the ciliary processes and the crystalline lens which crosses the eye close behind the ciliary processes. It is very nearly pure water, containing in solution a small quantity of common salt and albumen. It is enclosed in a membrane which is in contact with the inner surface of the cornea in front and the ciliary processes and crystalline lens behind.

360. The *vitreous* or glassy humour lies behind the crystalline lens, and occupies the whole of the posterior chamber of the eye, which is about two-thirds of the whole. It consists of a clear thin fluid enclosed in a membrane, which not merely surrounds it, but radiates inwards into its substance like the partitions of an orange, so as to make up a half solid gelatinous body, which is called the vitreous body, or posterior lens of the eye. These partitions are very numerous, and point to the axis of the eye, but do not reach to it, and consequently there is a central cylinder passing from front to back composed only of the fluid of the lens. The form of the vitreous body is convex behind, while before there is a deep cup-shaped depression for receiving the crystalline lens. The membrane that surrounds it on all sides, as well as enters the interior, has a twofold connection in front: it doubles in so as to receive the crystalline lens between its folds, and it unites with the ciliary processes, which surround the lens without reaching its border. Thus the partition between the aqueous humour in front and the vitreous humour behind is made up of three successive portions enclosing one another:

the wrinkled black ring of the ciliary processes outermost; within this a ring of the doubled membrane of the vitreous humour; and inmost of all, the crystalline lens enclosed between the two folds of the membrane.

361. The *crystalline lens* is a transparent solid lens, double convex in its form, but more rounded behind than before. It is situated between the aqueous and vitreous humours, and suspended in its position as already described. Its convexity in front approaches very near the curtain of the iris, which is stretched in front of it. The lens is enclosed in a capsule, of which the front portion is thick, firm, and horny, while the portion on the back is thin and membranous, adhering firmly to the membrane of the vitreous humour. The substance of the lens varies in its character: the outside portion is soft and gelatinous; beneath this is a firmer layer; and in the centre is the hardest part, called the nucleus. It is supplied with blood-vessels in the edges, but none appear to penetrate within, except in a very early stage of life. It undergoes altogether a great change in the course of the development of the individual. In the fœtus it is nearly spherical, and is not perfectly transparent; in mature life it is of the form and character described above; while in old age it becomes flattened on both surfaces, loses its transparency, and increases in toughness and density.

362. In the figure, RMN is the tough sclerotic coat, joining the cornea, RCN, in front. The lines *d d* point to the choroid coat, and *e e* is the retina; *g* points to the ciliary ligament, and *h* to the ciliary processes; *i i* is the iris, with the pupil in the centre; *a* is the aqueous humour, *b* the crystalline lens, and *c c* the vitreous humour; *f f f f* is the membrane of the

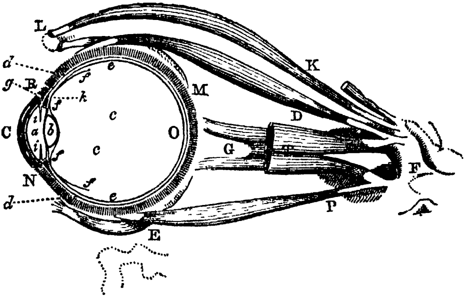

Fig. 66.

vitreous humour, which is purposely detached from its contact with the retina to make it visible; its inner fold, lying close to the ciliary processes, and passing inwards to the front of the crystalline lens, is also apparent.

363. Such are the chief portions of the ball of the eye. The optic nerve, O, which enters it obliquely at a point inward from where the axis passes through the back, is a strong white cord, nearly as thick as a quill, and is one of the means of keeping it firm in its place. The termination of the nerve is not shown in the figure, which is a section down the eye through the axis. Each eye is imbedded in loose fat, and floats easily upon it. The optic nerve and the fatty bed form its restingplace behind, and maintain it in opposition to the strain of the principal muscles when these act all together.

364. The eye is further retained in its place, and its delicate movements adjusted, by six muscles—four straight, and two oblique. The four straight muscles arise from the bony socket in which the eye is placed, around the opening where the optic nerve, O G, enters from the brain, and are all inserted in the anterior external surface of the eyeball, their attachments being respectively on the upper edge of the sclerotic, the under, external, and internal sides of the eyeball. The superior oblique or trochlear muscle arises from beside the origin of the superior straight muscle, and passing forward to a loop of cartilage, L, acting the part of a pulley in reversing the direction of its action, its tendon passes through the loop, and is reflected back and inserted on the upper posterior surface of the eyeball. The inferior oblique muscle arises from the internal inferior angle, at the fore-part of the orbit, and is inserted into the internal inferior surface of the eyeball, behind the middle of it.

365. Three of these muscles are represented in the figure. K L is the superior oblique or trochlear muscle, whose tendon passes through the loop, L, and thence backwards to its insertion M; E P is the inferior straight muscle, E being the place of its insertion; and F T is a portion of the interior straight muscle, which is cut off at T, to show the optic nerve beyond it.

366. The motions of the eyeball that would be caused by the contractions of any of these muscles are manifest. The inferior muscle, E P, by its contraction, will make the point E move towards P, or cause the eye to look downwards; the superior straight muscle will cause it to look upwards. The action of the trochlear is peculiar. Since it is reflected backwards from L to its insertion, it will turn the eyeball downwards and outwards—that is, the eye would by

its action look obliquely downwards and outwards. This muscle tends also to draw the ball of the eye a little outwards, or to make it protrude. The inferior oblique muscle having its origin on the outer part of the orbit, and its insertion on the inner side of the eyeball, will, by its contraction, also draw the eye outwards, and turn it upwards and outwards.

367. The four straight muscles are the voluntary muscles engaged in moving the eye for the purposes of vision. By their means each ball can be made to sweep round over the whole field of view, and perform the adjustments requisite for different distances. The two oblique muscles act in the involuntary movements, and in obedience to certain feelings and emotions. In sleep the eyeball is uniformly turned up by the action of the inferior oblique. The trochlear muscle is called also the *pathetic muscle*, being brought into play in bursts of tender emotion, and probably also in the darting glances which accompany laughter. The upward movements of the ball, happening at the moments of winking, with the view to wipe the surface more effectually, are involuntary movements of the inferior oblique, adjusted so as to accompany the movements of the upper eyelid.

FORMATION OF IMAGES ON THE RETINA.

368. When the eye is directed to any object, an image of the object is depicted on the retina by means of the rays of light that proceed from every point of it. Of all the rays which emanate from a single point of the object, only those enter the eye that fall on the pupil. These rays, in passing through the various lenses, are so refracted that they all unite again in a single point on the retina, at which a luminous impression is made, and a perception of that point of the object thereby produced.

369. Thus of all the rays emanating from the point A of the arrow A W (fig. 67), only those in the conical pencil of which A *i*, A *c* are extreme rays, and A *e* the axis, enter the eye; and these, after passing through the crystalline lens, form an

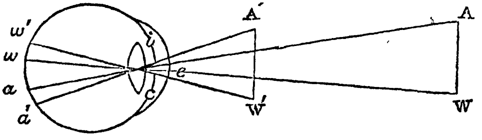

Fig. 67.

inverted conical pencil, whose rays all converge towards one point *a*, which is therefore the image of A. So *w* is the image of W, and all the intermediate points of the object between A and W have corresponding images between *a* and *w*. The whole image will be similar to the object, and of the same colour, but inverted.

370. By the three lenses of different material which make up the globe of the eye, an achromatic arrangement is produced, which is very nearly perfect for all distances: in other words, a compound achromatic eye-piece is the result. The choice of lenses of different density and character has the effect of correcting the dispersion that would arise from a single lens, and the images are thus rendered pure, and free from coloured fringes or prismatic phenomena.

APPARENT MAGNITUDE OF THE SAME OBJECT AT DIFFERENT DISTANCES.

371. The apparent magnitude of the same object when seen at different distances, depends on the size of its image on the retina. When at double the distance, its image is half the size; and generally the linear magnitude of the image of the same object at different distances from the eye is inversely as the distance.

372. Thus if *a w* (fig. 67) be the image of the arrow A W, and *a′ w′* its image when at A′ W′, half as distant, the latter image will be twice as great as the former. Also the angle under which the object appears, formed by lines drawn from the eye to its extremity, called the *visual angle*, is in nearly the same proportion as the size of the image or the apparent magnitude. Thus the visual angle A′ *e* W′ is about double the angle A *e* W when the distances of the object from the eye are as 1 to 2.

VISION.

373. The apparent magnitude of the same object depends, as we have seen, on the distance at which it is placed, and diminishes very nearly in the proportion in which the distance increases.

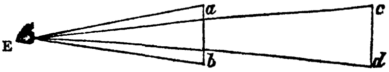

Fig. 68.

374. Thus if the object *c d* (fig. 68) be equal in length to *a b*, and twice as far distant from the eye, the visual angle *c* E *d* formed by the

first is only about half of that formed by the second, or *a* E *b*.

375. When the real size of an object is known, we judge of its *distance* by means of the visual angle. The distance of objects is also judged of by their degree of brightness and their colours; a blue-looking mountain is always considered to be distant, the blue colour arising from the great extent of air through which it is seen. We are likewise enabled to judge of the distance of an object by means of intervening objects; and when few objects intervene, we generally consider the remote object nearer than it actually is; as in the case of a ship at sea, or the heavenly bodies. On account of the great number of intervening things between us and the rising moon, and also on account of the diminution of brightness in looking through such an extent of misty horizontal air, the moon appears much larger than when far up in the sky. For the same reason an arc in the heavens, near the horizon, appears larger than an arc of the same extent at a greater altitude.

376. Another means of judging of the distance of near objects is by the inclination of the optic axes of the two eyes. These axes are always directed to the point we are looking at; hence when the point is near, the inclination of the axes will be greater than when it is more distant, and the feeling we have of the actions of the eye will make known to us the degree of inclination, and thence the distance.

377. When the cornea and crystalline lens have their just degrees of curvature, and the eye is of a proper length, the images of objects not too near are formed exactly on the retina. But when the curvatures are too great, they cause the rays to converge prematurely, and the image is formed before the retina; and a pencil of rays, after crossing at any point of this image, becomes a conical pencil of diverging rays, whose base is a small circle on the retina, and this circle is the image on the retina of the corresponding point of the object. Thus the images on the retina of all the points of the object are small circles that overlap each other, and produce an indistinct and confused image. Such an eye is said to be *myopic*, and the person is said to be *short-sighted*. The mode of correcting this imperfection is to use a concave lens, which causes the divergent rays incident on it to separate in some degree—that is, to become more divergent; and consequently on entering the eye they will have a less rapid convergence, and the image will be formed on the retina, and produce distinct vision.

378. Thus if, from the peculiar form of the eye, rays pro-

ceeding from an object B (fig. 69) form an image before the retina, by interposing the lens L L, their convergence within the eye will be lessened, and the image formed at R on the retina.

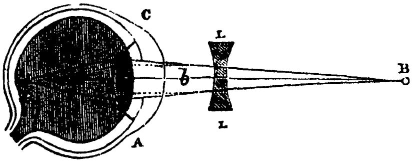

Fig. 69.

379. If, again, from a too small curvature of the cornea and crystalline lens, or from the eye being too short, the rays do not converge till they pass beyond the retina, supposing it transparent, so as to form an image behind it, there will arise in like manner a confused picture of the object. A person with an eye of this form is said to be *long-sighted.* A convex lens interposed between the object and the eye corrects this defect of vision.

380. Let rays from the point B (fig. 70) falling on the eye A C converge to a point R, then they would form a circular image of the point on the retina at *d*. But the lens *m n* being interposed, causes the rays to converge quicker; and if it has the proper curvature, they will converge to a single point *d*: the same will happen to rays from every other point of the object; consequently a distinct image will be formed.

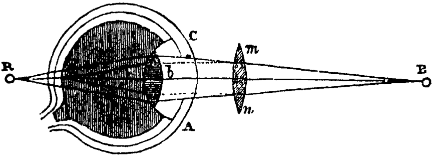

Fig. 70.

381. If an object *o* (fig. 71) be nearer to the eye than the nearest distance of distinct vision, which is from 6 to 10 inches, the rays will not converge quick enough, and a convex lens must be used, as in the case of a long-sighted person.

Fig. 71.

382. *Questions connected with Vision.*—There are various

points connected with vision that have given rise to discussion and difference of opinion, from the difficulty that there is in deciding them with certainty in any one way.

383. The first of these relates to the *Seat of Vision*, or the surface immediately acted on by the rays of light entering the eye. There are two suppositions on this head—the one, that the *retina* is the surface of vision; the other, that the *choroid coat* is the medium acted on and stimulated by the rays in the first instance. The reasons in favour of the last supposition seem to predominate, being as follows:—

1*st*, The retina is a transparent coat, allowing a free passage to the light, and therefore not likely to be acted on itself by the rays. On the other hand, the choroid coat is black, and absorbs and stifles the whole of the luminous influence; consequently, whatever effects light is capable of producing on material surfaces, must be produced to the utmost possible degree on the black pigment of the choroid.

2*d*, In the other senses there is usually a sensitive surface, distinct from the fibres of the nerve of sense. In touch, the skin is the sensitive surface; in hearing, the liquid contained in the labyrinth is the medium of acting on the nerve; and in smell and taste there appear to be sensitive membranes, which are affected in the first instance. Hence we derive an argument from analogy in favour of the existence of a distinct sensitive surface, apart from the transparent expansion of the optic nerve.

3*d*, No sufficient reason can be rendered for the existence of a membrane like the choroid, so richly endowed with blood-vessels—the mark of intense activity—if it is not to serve as the sensitive surface of the eye. If it is intended for no other purpose than to swallow up and destroy the light, after it has served its end by acting on the retina, the inference would be that too much light enters the eye for the purposes of vision, and that it is necessary to provide some surface for extinguishing the great body of it. But the difficulty we have in seeing distinctly with much less than the average quantity of light proves that this cannot be the case, and that some use is made of the portion that passes clear through the retina. If only the small amount arrested by the transparent retina were required for vision, much less illumination ought to serve than we actually need.

4*th*, At the place where the optic nerve enters the eye, to the inner side of the central hole in the line of the axis, the choroid coat is interrupted, and *rays falling there produce no vision.* In fact the spot over the optic nerve is termed the *blind point* on this account. But the retina is not deficient at that point; we are therefore driven to conclude that it is the absence of the choroid that causes the lack of vision, and that it is indispensable that the stimulus of the light should affect the black pigment in the first instance, from thence to be communicated to the retina.

384. If these reasons are conclusive, we must infer that the rays of light pass through the transparent retina, and bury themselves in the black pigment of the choroid; that, spending their whole might there, they produce some atomic change in the particles of the pigment, which cannot in our present state of knowledge be specified; that the change or activity thus generated is transmitted by conduction through the rods of the membrane of Jacob, whose points are in contact with the membrane of the pigment; that through these rods the activity passes to the layer of nerve-cells lying beneath the nerve-fibres of the retina, and, through the cells, affects the fibres themselves, which, being by nature conductors of impressions, convey inwards to the brain the influence or stimulus thus imparted. No surface is so powerfully affected by light as one that is black, and hence the propriety of employing this kind of surface for receiving the impression in the first instance. The greatest possible amount of influence is in this way generated for communication to the adjoining nervous cells and fibres.

385. Another question connected with vision is *the mode of adjusting the eye to distance.* If the eye is considered as a lens, and if it forms on the retina or choroid coat an accurate image of a certain object, the images of all objects, either at less or at a greater distance, will be confused and inaccurate: in the one case the focus of the image will be behind the retina, and in the other case before. Consequently some adjustment must be made in transferring the glance from a near to a distant point, or from a distant point to a near. If the eye could be flattened or elongated from before backwards, the requisite adjustment would be made—that is, if in proportion as we extended our regards to a great distance, the eye could be squeezed, compressed, or made shorter from front to back, the retina would be made to coincide with the focus of rays proceeding from the object, and the vision would be clear and distinct. Now it is likely that such a squeezing of the firm ball of the eye actually takes place by the conjoint action of the four straight muscles, and that the eye recovers by its natural elasticity when the action of the muscles ceases. No other means of adjustment can be distinctly pointed out apart from this muscular effort counteracted by the elasticity of the ball; and the employment of such means is confirmed by

what we feel on such occasions. We are conscious of a great muscular tension within the sockets when looking at the distant landscape, and the position of ease for the eye is when viewing something near, or when the eyeball is not compressed by muscular effort. It is doubtful whether the two oblique muscles act in the opposite direction to the straight muscles, or whether they contribute to the lengthening of the eye in order to make us see near objects; but it is not impossible that they may, especially in the effort to look at objects very close to the eye, or within the limits of easy vision.

386. The third question relates to the mode of obtaining *single vision from two eyes.* It is a fact that when the same pencil of light affects similarly situated points in the back wall of both eyes, only one point is perceived by the mind; but if one of the eyes is so distorted that the same pencil falls upon points that do not correspond, a double image is seen. The presumption from this fact is, that the two optic nerves are, as it were, the division of one nerve, instead of proceeding inward to the brain apart; in other words, there is but one central group of fibres, and each of these divides into two branches, proceeding one to each eye. Our knowledge of the action of the brain is too imperfect to enable us to give a more precise account of this peculiar mechanism.

387. The fourth question concerns *the seeing of objects erect by means of an inverted image on the retina.* It has seemed to many people that because the images on the retina are inversions of the original object, we ought therefore to see all things upside down. But this notion is founded on an entire misapprehension of the nature of vision. An object seems to us to be up or down according as we raise or lower the eye in order to see it: the very notion of up or down is derived from our sense of movement and pressure, and not at all from the optical image formed on the back of the eye. Wherever this image was formed, and however it lay, we should consider that to be the top of the object which we had to raise our eyes or our body to reach. In making this point a question at all, it is imagined that the image formed by the eye is viewed behind as if by a second eye, which would of course discern an inversion, and not a truly placed image. But there is no ground for any such imagination.

IMAGES OF THE EXTERNAL WORLD.

388. The great purpose of the eye is to make us aware of the colours, forms, and situations of the objects of the external world; and this it does partly by its optical apparatus,

and partly by the muscles that sustain its various movements.

389. The optical portion of the eye reveals nothing but superficial light, shade, colour, and the absence of colour. The various bodies in nature have the power either of giving off rays of light of themselves, or of absorbing and emitting light derived from without—that is, all material bodies apparent to the sight are either self-luminous, like the sun and terrestrial fires, or are luminous by derivation, like the larger proportion of the world's surface, which shines by borrowed light. If we except white and black surfaces, almost every different substance emits light of a colour and shade peculiar to itself, from the peculiarity of its texture, which determines the mode of the decomposition of the light falling on it, or the particular portions of the solar beam that are to be emitted. A red body is one that stifles and buries all but the red ray; a black surface absorbs all the colours, and emits none; a white body, on the other hand, sends out the solar light complete and undecomposed.

390. By the impressions made on the retina being transmitted inward to the brain, there is produced the consciousness we have of colour or illumination. By the eye being directed outward, through the tension of the straight muscles, we have the notion that the cause of colour lies *without ourselves* at some distance, more or less—the feeling of distance depending on the degree of muscular tension requisite to produce a distinct image. When the four muscles, acting together, have to put forth all their might in order to make the image distinct, we believe not only that the original is without us, but that it is at some very great distance off, or that we should require to move our body a long way if we wished to come close up to it. Our first notion being the feeling of *outness*, and our second that of *distance*, the third is the feeling of lateral dimensions, or of length and breadth, and of the combination of the two, which is *expanse*. Mere luminous impressions, if unaccompanied with the feeling of the movements and sweep of the eye, would never give us the sense of outstretched space, any more than they would give the assurance of the externality and remoteness of the luminous body.

391. The sense of expansion, or of superficial extent, combined with the sense of distance, and of approach or retreat from the eye, would give the feeling of *solidity*, or of three dimensions; but it has been shown by Professor Wheatstone that the vivid conception we have of solid forms arises from the conjoint action of the two eyes upon one and the same body. Since the eyes are some distance apart from each

other, if they are directed upon any object they will see different faces of it—the right eye will see one aspect or surface, and the left eye will see a different aspect, as if viewed from a point to the left. Now the coalition of the two aspects, or the embrace of the object between the two glances, has the effect of giving a distinct and strong impression of solidity, an effect which has been imitated by Professor Wheatstone by means of an instrument called the *stereoscope*, where two different views or drawings of an object, taken from points a little apart, are made by mirrors to be viewed by the two eyes separately. At the moment the two images coincide in the view, or cover one another, a solid body seems instantaneously to start out, and the illusion of the perspective is complete.

392. The eye is formed to take into its view a very wide sweep of the surrounding scene at one time; with both eyes open at once rays from nearly one-third of the whole sphere are admitted; but accurate vision takes place only within a very narrow spot—namely, at that part of the scene where the axis of the ball is directed, or straight before the eye. The colour, distance, linear dimensions, and solid form of an object thus directly seen, are distinctly ascertained, and, by a law of nature, leave an impression behind them which may remain or be recalled in the absence of the original. And it is by causing this direct glance to pass hither and thither over the whole field of view that we form an accurate conception of all that is within the sweep of our vision. Hence it happens that the eye in the act of seeing is never at rest, but flits incessantly about from side to side and from near to far, mixing up feelings of movement and activity with sensations of colour, outline, and form. When we look out upon a varied expanse of scenery, we are apt to suppose that we see the whole at that moment, but in truth it is our past impressions coming up along with the present that give the fulness to the picture. Almost the only thing we recognise in the circumference of the area of sight, is whether or not any part of it presents anything to attract a more special glance; if a change or new appearance start up, we feel the change, but we have no clear perception of form and minutiæ farther than old recollection gives us. The retina of the eye has its sensibility developed most intensely in the neighbourhood of the central aperture, and as we recede from that its impressions are more and more vague and imperfect. Hence the eye is adapted for distinct vision chiefly at the point of concentrated attention, directly in front of the ball, or in the line of its axis; and when we wish to examine minutely any other portion of the field of view, it can be done only by turning the eye full upon

that portion. But in addition to the physical difficulty of taking in a wide field at one glance, there is a mental difficulty still more insuperable; for it is impossible for the human mind to attend to more than one thing at a time, however rapidly it may pass from one object to another. Consequently whatever exists as one complete whole may be attended to, but we cannot divide the attention between different wholes except by taking them turn about. When, therefore, we wish to picture to ourselves a wide scene, we must abandon all attention to its details, and look upon it simply in its outline, or general expanse and form.

393. The characteristics of the eye in the susceptibility to colour differ in different individuals. Some eyes are destitute of black pigment, and have, in consequence, a dull white appearance, instead of the shining black pupil and coloured iris: the effect of this is necessarily to render sight very feeble and imperfect, a white surface being so much less susceptible to light than the black pigment expressly provided for receiving the full force of the rays. But there are eyes not destitute of pigment, which nevertheless are not correctly impressed with colours. Cases occur of individuals who either mistake one colour for another, or fail to discern the difference between the greatest contrasts. This is analogous in its nature to the entire want of a musical ear, though a far more serious defect. Great delicacy in the sensitiveness of the choroid and retina to colours and shades of intensity has a deep influence upon the whole character of the individual, giving a fine perception of landscape and pictorial beauty, and a taste for all the arts of coloured decoration.

394. *The duration of the impression of light* is an assignable period, although only a small fraction of a second. The familiar experiment of making a circle of light by whirling a burning stick is a proof of it; and the same principle is applied to produce certain optical illusions. A card with a soldier on one side, and sentry-box properly situated on the other, may be so rapidly twirled that the soldier shall appear standing in the box; and an infinite variety of combinations on the same principle may be produced. Also it takes a certain length of time to make an impression on the eye: an object may fly past so quick as not to be seen.

395. The *harmony of colours*, as well as of sounds, is founded on physical reasons. When the eye has to pass from one colour to another beside it, the pleasure of the transition will be greatest if the colours be *complementary*—that is, if they are such that the union would produce white light. If we were to deprive the solar beam of its red rays, and combine

all the rest into one colour, that colour would be green; red and green are therefore called complementary colours. Both together, in proper proportions, would make pure white. Now, since white is the balance and perfect harmony of all the colours, and the effect that can be endured with the greatest intensity for the greatest length of time, an eye acted on by one of the simpler colours desiderates the complement of that colour to balance its action on the nerves. Thus, after being much exposed to a yellow radiance, we derive especial enjoyment from blue; yellow and blue being complementary colours, like green and red. Wherefore in the union of colours in works of art and design certain conditions are imposed by the nature of light, and these cannot be violated without producing effects the opposite of pleasing. The desire of strong unbalanced colours shows an absence of artistic feeling, and the love of pungency of sensation. Red is the most intense of all the colours, and gives the strongest stimulus to the nerves of sight; but it is for that reason more apt to fatigue the organs. Its complement green, on the other hand, is perhaps the most endurable of all the colours. White and black harmonise in any proportions, inasmuch as the eye is always prepared to pass from light to darkness, and can find refreshment in so doing.

PHYSICAL OPTICS.

396. The term *physical optics* is properly applied to the exposition of the physical causes of optical phenomena. It is treated under the heads of *interference, diffraction, polarisation,* and *double refraction* of light. As scarcely any of the phenomena are capable of explanation on the material theory of light, while nearly all of them can be explained on the principles of the undulatory theory, and none are contradictory to it, we shall adhere exclusively to the latter theory.

INTERFERENCE OF LIGHT.

397. The interference of luminous waves is so exactly similar to the case of sonorous waves, that it is unnecessary to give a minute account of it, excepting in some points peculiar to itself. The vibratory motion of a particle of ether, instead of being in the direction of propagation, as in the case of aërial waves, is in a plane perpendicular to that direction, and similar to the vibrations of a particle of water when the surface is disturbed.

398. Thus let A B D E F (fig. 72) be a straight line of ethereal particles at rest; after being put into a state of vibration, they will be found in the waved line B d D s E m F; the particle formerly at c being now at d, while that formerly at t is now at s; and so on. The path def described by a particle is an ellipse, and in a plane perpendicular to A B D, which is the line of propagation of the wave. The elliptic paths described by a great number of consecutive particles will be nearly in similar positions, and of the same magnitude, though not exactly so; they will in general gradually alter in these respects, sometimes in one way, and sometimes in the opposite way, but not necessarily with perfect regularity. While a single particle, as c or o, describes its

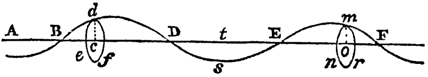

Fig. 72.

elliptic path *d e f*, or *m n r*, any point of a wave, such as its foremost extremity D, will move to F over the breadth of a wave; and the motions will be similar to those already described in reference to waves of water. As in the case of water and undulatory motions generally, the particles of the medium have no progressive motion, their motion of translation being very small and reciprocating.

399. From the above explanation, the *interference* of rays of light will be readily understood. When two undulations of waves of equal length, whose directions are slightly inclined, meet at any point *m* (fig. 73) in the same phase, the effect of their vibratory actions is to move the point *m* in the same direction; and they thus strengthen each other, or conspire to produce light of double intensity.

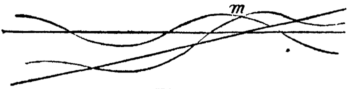

Fig. 73.

400. But when the rays meet in opposite phases, their motion tends to impel a particle, as *m* (fig. 74), in opposite directions; and when the vibrations and lengths of the waves of the two rays are equal, the opposite forces acting on *m* destroy each other, and the point remains at rest; so that if the rays were received on a screen at that point, there would be no illumination. When the two rays meet in any other phases than the same or opposite phases, the intensity will be intermediate between nothing and double the intensity of one of them. A remarkable fact in the motion of minute waves is, that when two rays interfere on meeting, so as mutually to destroy each other, they proceed beyond the point of interference, and recover their former intensity just as if no interference had taken place. This result is in perfect accordance with the theoretical principles of interference, and is illustrated by the analogous case of two musical strings that are so nearly in unison as to produce a sensible beat.

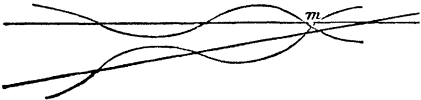

Fig. 74.

401. One of the simplest illustrations of the principle of interference is the following, invented by Young:—Two small holes are bored very near each other in a thin metallic plate, and divergent pencils of light passing through them are received on a screen placed at a sufficient distance to allow the pencils to cross each other before falling on it; then a series

of bright and dark bands are formed on the screen by the interference of the rays, the direction of the bands being perpendicular to the line that joins the openings.

402. Thus let O, O′ (fig. 75) be the holes, and F F′ the screen, and let the rays O C, O′ C proceeding to the point C have equal paths from O and O′ to C; if they be in the same phase when at O and O′, they will still be in the same phase at C, and will therefore conspire to produce light of more intensity than either of the rays separately. So at a point D, such that the lengths O D, O′ D of the paths of the rays meeting in it differ exactly by a whole wave, the waves will again meet in the same phase, and produce light of greater intensity than either of them alone could yield. D will therefore be a bright point; so D′ at the same distance on the other side of C will also be bright. If, again, the paths of the rays meeting in F differ by two waves in length, F and F′, equidistant with F from C, will also be bright. And all points situated so that the difference of their distances from the points O, O′ is a whole number of wave lengths, will be bright. But between every two bright points there will be a dark point. For at some place *e*, between C and D, the difference of the paths O *c*, O′ *e* will be a half wave; and therefore any point of a wave of one of the rays will always meet with a point of a wave of the other ray in an exactly opposite phase, and the two rays will constantly destroy each other at that point. So at some point *c*, between D and F, the difference of the distances O *c*, O′ *e* will be 1½ waves, and the two rays will therefore meet in opposite phases, and cause darkness. It thus appears that at all points so situated that the difference of the lengths of the paths of the two rays meeting them is ½, 1½, 2½—that is, 1, 3, 5—*half* waves, or an *odd* number of half waves, there will be darkness.

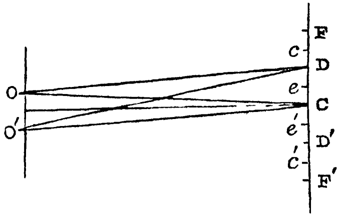

Fig. 75.

403. The best form of the apertures is a thin slit or rectangular opening about $\frac{1}{40}$ of an inch in diameter, and ½ inch long; the two being parallel to each other, and at a distance of about $\frac{1}{30}$ of an inch. The experiment must be performed in a dark room.

404. The interference-prism is an isosceles prism, its two

equal sides being inclined to the third side at a very small angle, so as to be nearly in one plane. A ray of light from a minute origin, as the reflexion of a sunbeam from the bulb of a thermometer, being incident perpendicularly on its base, the two rays emerging from the equal sides interfere, as in the case of the two apertures.

405. In the preceding experiments, when homogeneous light is used—that is, light of one colour—a great number of fringes may be observed; but when white light is used only a few are seen. The cause of this is as follows:—The lengths of the waves of different colours are different; the wave of the extreme red is nearly double the length of the wave of extreme violet; therefore the intervals between the violet stripe, when violet light alone is used, would be only about half the intervals of the stripes for red light; and for intermediate colours the intervals will be intermediate between these extremes. The bright stripes for one colour, therefore, when white light is used, will not always coincide with the bright stripes of the other colours, but will sometimes fall on the place of the dark stripes corresponding to other colours. On this account the stripes will appear to consist of various-coloured light, and they will be rendered indistinct by the diffusion and blending of the light of different colours.

406. The interference of light caused by transmission through *thin plates*, or by reflexion at their surfaces, external and internal, produces a variety of striking appearances. The light reflected from the nearer or external surface, and that from the farther or internal surface, meeting in various phases, produce alternations of bright and dark points. Thus if A B C (fig. 76) be a very thin plate of glass, whose sides are slightly inclined, and on which light is incident in the direction I E, a portion of it will be reflected at its first surface, in the direction E R, and another portion of it, after reaching the internal surface at F, will be reflected back through the plate, and will emerge upwards in a direction nearly parallel to E R. These two portions will interfere with one another; if the thickness E F of the plate be ½ the length of a wave, the light reflected back at F will traverse the plate twice, and will be two half-waves, or *one whole* wave, behind the wave reflected at E, and will therefore, on emerging, meet the light reflected at E in

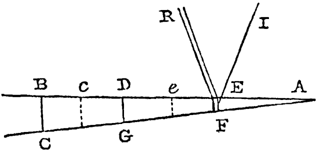

Fig. 76.

the same phase, and the two together will produce bright light. The same will happen at D, where the thickness is *one* wave-length; for the light reflected at G will, on emergence at D, be *two* whole waves behind, and will thus be still in the same phase with that reflected at D. The same will happen whenever the thickness is any whole number of half waves, or an even number of ¼ of a wave. Again, at *e*, *c*, ... and other points where the thickness is any odd mutiple of ¼ of a wave, there will be *dark* stripes; for on these points the ray reflected at the second surface would, on emergence, meet the light reflected at the first surface in an opposite phase. The bright and dark stripes, therefore, whether for homogeneous or for compound light, will be exactly analogous to the fringes explained above. The transmitted light produces similar fringes.

407. The above explanation is not strictly true, on account of the fact, that the direction of vibration of the particles of ether is changed when light is reflected at the surface of a medium denser than that in which the incident light is moving. The effect of this circumstance is just to interchange the positions of the bright and dark bands as described above; that is, the first bright band will be where the first dark band was described to be; or these two bands just change places; so do the second bright and dark bands; and so on.

408. If instead of a plate of glass, a very thin lens is used, the fringes will be of the form of successive rings around the centre of the lens. When the plate is a thin film of air contained between a plate of glass and a lens pressed hard together, the rings that are formed are called *Newton's rings*, as they were first investigated by him in this form. Instead of the wedge-shaped plate described above, a thin film of air confined between two glass plates will produce the same effect.

409. It is to be observed, that the motion of light within a refracting medium is slower than in air, and the length of a wave is also less.

410. If a thin plate of glass is held across the pencil passing through one of the apertures, as O′, in the experiment of art. 402, the place of the fringes will be altered, though their relative position is undisturbed; which proves that the velocity in passing through the plate is different from that in air; and as the fringes are moved towards the side at which the plate is held, the light must be retarded in its transmission through it.

411. The interference of the light reflected from finely-scratched surfaces, as when glass or polished steel-plates have very fine parallel grooves cut on their surfaces, exceeding

3000 to an inch, produces beautiful coloured bands. The changeable colours in the feathers of birds depend on the same cause.

DIFFRACTION OF LIGHT.

412. The *diffraction* or inflexion of light is a change in the direction of the rays in passing close by the edges of bodies, by which it is bent inwards and illuminates the shadow to a small extent with bright fringes separated as before by dark intervals.

413. If light proceeding from a minute origin (as from the focus of a lens of small focal distance, or from a straight narrow aperture, or by reflexion from the side of a thin glass tube blackened within) be made to pass the edge of an opaque body, there will be observed in the shadow three or four bright fringes.

414. Thus if O be the origin of the light (fig. 77), B D the opaque body unlimited towards D, and H L a screen, S H will be the geometric shadow; but the real shadow will be less; for B T being the front or cross section of a circular or rather spherical wave of light proceeding from O, by the principle of undulation a minute wavelet will proceed from every point of B T, and in all possible directions, and at some point, such as *m*, the illumination from these wavelets (or partial or *secondary* waves, as they are termed) will be a maximum, and at some other point, as *n*, it will be a minimum; so between *m* and H there will be other similar points of maximum and minimum intensity. In this way the dark and coloured bands above-mentioned are formed. The fringes thus produced may be called the *single* system of fringes.

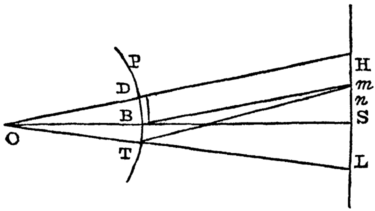

Fig. 77.

415. When the body B D is a wire or needle $\frac{1}{20}$ or $\frac{1}{50}$ of an inch in diameter, another set of wavelets proceeding from D P enter the shadow, and interfere with those inflected from the edge B; and thus a new system of fringes is formed, which may be called the *double* system. In this case the band in the middle of the shadow is a bright one; a singular effect depending on the same cause as the bright band at C in the experiment of art. 402.

416. If light from a minute origin is transmitted through a very narrow slit in a card, or in a metallic plate, there will be not merely a bright band formed on a screen held opposite to the plate, but on both sides of the bright line a series of dark and bright bands, caused by the interference of the wavelets proceeding from the front of the waves in the opening. It is found that the breadths of the fringes depend on the breadth of the aperture, and that these breadths are nearly in an inverse ratio; the wider the aperture, the narrower are the bands. The same relation holds between the breadth of the narrow opaque obstacle formerly mentioned and the fringes in the shadow.

417. If we look through the opening just described at a narrow line of light, or even at the flame of a candle 5 or 6 yards distant, the light will be observed with several coloured images of it on each side. With violet, or yellow, or red light, the bands would be of the respective colour separated by dark intervals: the violet bands would be closest, as the uppermost seen in the adjoining figure; the red widest; and the yellow intermediate.

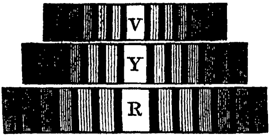

Fig. 78.

POLARISATION OF LIGHT.

418. A ray of light, after reflexion at a certain angle from the surface of any body, is found to have undergone a remarkable change in its nature. To the unaided eye it appears to possess only the attributes of ordinary light; but when certain tests are applied to it, it is found to have acquired new properties. Thus let I *e* (fig. 79) be a ray incident at an angle of 33° on a plate of glass P, and let it be reflected in the line *e c* to another plate L, so situated that the angle of incidence on it is also 33°, and that the new plane of incidence *e c* R coincides with the first I *e c;* then the light will be reflected from the second plate in the ordinary way. But if the new plane of incidence *e c* R is perpendicular to the former, there is *no*

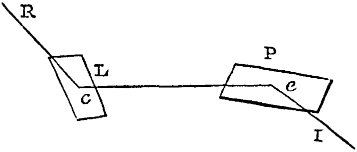

Fig. 79.

light reflected. The ray *ec* is therefore quite different from ordinary light.

419. The ray *ec*, reflected at the first incidence, is said to be *polarised;* and the angle at which this effect happens is called the angle of *polarisation.* When light is transmitted through certain crystals, called double-refracting crystals, it is found to be similarly polarised. When Newton, in experimenting with two such crystals, observed this change in the nature of the light, he remarked that certain properties on certain *sides* of the rays were adapted to some property of the crystal, "as the poles of two magnets answer to one another." In other words, he considered the particles of light to be possessed of a species of *polarity;* and hence the origin of the term polarisation.

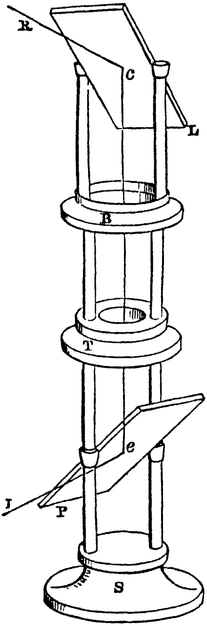

Fig. 80.

420. The plates of glass used as reflectors are not silvered mirrors: they are merely blackened on the back, as by covering them with black wax; or they may consist of eight or ten thin plates applied close together. If the two plates P, L are fixed on a board, and the second, L, made movable about an axis, so as to vary the plane of incidence, the instrument will then form a polarising apparatus; which, when furnished with graduated arcs for measuring the angles of incidence, and the inclination of the two planes of incidence, is called a *polariscope.* The first plate, P, is called the *polarising plate;* and the second, L, the *analysing* plate; and the first reflected ray, *e c*, is said to be *polarised in the plane of incidence;* or in other words, the plane of incidence I*e c* is said to be the *plane of polarisation* of the ray.

421. A convenient form of the polarising apparatus is represented in the adjoining figure. The polarising and analysing plates, P and L, correspond with those in the last figure. The ring B, to which the upper plate is fixed, is movable in the wider ring in which it is placed, so that the plate can be turned to any *azimuth,* as it is termed; and the angles of incidence on both

plates may be varied at pleasure. If the circumference of the outer ring, B, is divided into 360°, the inclination of the two planes of incidence can then be measured.

422. Different substances are found to have different angles of polarisation. Malus, who first observed the incapability of a polarised ray to be reflected at the angle of polarisation, when the plane of incidence is perpendicular to the plane of polarisation, also observed the polarising angles of a variety of substances; and Sir David Brewster made further observations of the same kind, and finding that these angles increased with the refracting power, he observed that the tangent of the angle of polarisation is equal to the index of refraction; which relation, with a multitude of others discovered by other experimentalists, is found to be a direct consequence of the undulatory theory of light.

423. The two mirrors P, L being placed at an angle of 33° with the vertical line *ce*, and the analysing mirror being placed so that its plane of incidence R*ce* coincides with the other I*ec*; then, on the eye being so situated as to receive the ray R*c*, it will be found, as was said above, that the light is reflected like ordinary light; but if the ring B, to which the second mirror is fixed, is made to turn one-fourth round —that is, 90°—either to the right or left, no light is reflected from L; but if the ring makes a complete revolution, the light is again reflected, as in the first position of the mirrors. By placing doubly-refracting crystals on the stage T, so that the vertical ray may pass through them, a great variety of beautiful phenomena are observed, exhibiting brilliantly-coloured curves arranged in a perfectly symmetrical manner.

DOUBLE REFRACTION.

424. Most crystallised transparent bodies, when light from any object is transmitted through them, present two images of the object; and hence their name of *double-refracting crystals.* The two refractions by which the two images are formed observe different laws. In certain of these crystals it is found that the internal refracted ray is only *single* when it passes through the crystal in a particular direction, which is called the *optic axis* of the crystal; in other crystals there are two particular directions in which the refraction is single, which are also termed the *optic axes* of the crystal: the former crystals are consequently termed *uniaxal,* and the latter *biaxal.* In uniaxal crystals, one of the rays follows the law of ordinary refraction, so that the ratio of its sines of incidence and refraction is constant, whereas the other ray follows a variable

law, dependent on its inclination to the optic axis; the one ray is thus subject to *ordinary*, the other to *extraordinary* refraction; the former is consequently termed the *ordinary*, the latter the *extraordinary ray*. In biaxal crystals, both rays observe a variable or extraordinary law.

425. The Abbé Haüy, about the end of last century, when studying the classification of minerals, turned his attention to their crystalline characters; and finding that a great proportion of them were double-refracting crystals, he adopted this property as an important means of determining the classification of crystals. In generalising the results of his observations, Haüy states in his "Mineralogy," that all substances whose integrant molecules are remarkable for symmetry have *single* refraction; which substances, according to his system, are those having for their *primitive form* the cube, the regular octahedron, and the rhomboidal dodecahedron. In his time, however, the primitive forms of some crystals, and the nature of their double refraction, were imperfectly known; and he has consequently made several mistakes in his arrangement of these crystals. Afterwards Sir David Brewster observed that the greater number of crystals is biaxal. In classifying doubly-refracting crystals according to the improved system of Mohs, he arranged the *single-refracting* crystals under the tessular; the *uniaxal* he found to belong to the rhombohedral or pyramidal; and the *biaxal* to one or other of the prismatic systems.

426. So early as the middle of the seventeenth century, Erasmus Bertholinus, a physician in Copenhagen, got from some Danish merchants, who frequented Iceland, specimens of a crystallised and transparent mineral, called, from their native locality, Iceland crystals; and Bertholinus was the first to observe, or at least to examine critically, the remarkable property of double refraction possessed by them. · The primitive form of this crystal is a regular rhombohedron; that is, a solid contained by six plane sides, every opposite two of which are parallel, and the planes equal rhombuses. When the figure of the crystal is different from this, it can always be reduced to it by splitting with a knife in the direction of its planes of cleavage.

427. The following figure represents one of the regular rhombohedrons of a crystal of Iceland spar, which, for its easy cleavage, its transparency, and its high double-refracting power is one of the most useful substances in experimenting on or illustrating this subject. The angles of each of the six rhombuses are 78° 5′, and 101° 55′; and the inclinations of the faces, or the *dihedral angles*, are 74° 55′, and 105° 5′. The

trihedral, or solid angles at A and X, are contained by three equal obtuse angles; and hence they are called the *obtuse angles of the crystal;* the diagonal that joins the angular points of these two angles is the *axis of the crystal,* or its *geometric axis*—namely, A X; and its *optic axis* is any line whatever within the crystal that is parallel to its geometric axis; so that the latter axis coincides only in direction, and not in position, with the former. The optic axis is considered as passing through the point of incidence of any ray, as through the point I, and it always coincides with the axis of an integrant crystal situated at that point. A plane passing through the axis of the crystal, and perpendicular to one of its faces, is called a *principal plane* of the crystal, as A B X C; a plane perpendicular to it may be called the *co-principal plane.*

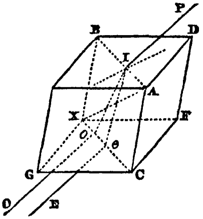

Fig. 81.

428. Let P I be a ray incident in a principal plane of the crystal; then it will be divided within the crystal into the two refracted rays I *o* and I *e*, the ordinary and extraordinary, and both will lie in the principal plane, which in this case coincides with the plane of incidence; though generally the extraordinary ray does not lie in the plane of incidence, the ordinary ray being always in this plane; and the extraordinary ray will be farther from the optic axis than the ordinary one; the axis being a line through I parallel to the axis of the crystal A X. Both rays, on emergence, proceed in directions *o* O, *e* E, parallel to the incident ray P I.

429. The two rays into which the incident ray is divided are of equal intensity; but they are found by the proper test—such as the polarising apparatus—to be both polarised, and in planes at right angles to each other; one in the principal, and the other in the co-principal plane.

430. These properties of the crystal may be observed by viewing a small object through it, in which case two images will be seen; or by placing a lens on its face, and passing the light of the sun or of a candle through it, when two images of the sun or flame will be formed at the focus of the lens; or by covering one face of it with a piece of card perforated by a small aperture, through which, in a dark room, light of sufficient intensity is made to pass, and the direction of the two rays will be distinctly observed by receiving them on another piece of card.

431. When the incident ray is perpendicular to a face of the

crystal, then the ordinary ray within the crystal, and its emergent ray, are in the same straight line with the incident one, although the internal extraordinary ray is inclined to the ordinary one at an angle of 6° 12′. If the crystal is laid on a sheet of paper, on which is a black dot, and if the eye is held above the crystal and directly over the dot, and the crystal be made to turn round, its face remaining always in contact with the paper, the ordinary image of the dot will remain stationary, but the extraordinary one will describe a circle about the other as a centre; the two images always lying either in the *shorter* diagonal C X, or in a line parallel to it—that is, in the principal plane.

432. If two artificial faces are formed on the crystal by cutting it in the direction of a plane perpendicular to the axis, and if a ray is incident perpendicularly on one of these faces, there will be only a single refracted ray in the direction of the incident ray—that is, in the direction of the axis itself; which proves that there is an absence of any doubly-refracting power in this direction. Any plane through the axis of this crystal is a *principal plane;* when a ray is incident obliquely on this face, there are as usual two refracted rays, which both lie in the principal plane that coincides with the plane of incidence; and the extraordinary ray has always the same degree of refraction around the optic axis when the incidence is the same; consequently the phenomena of double refraction are symmetrical about the optic axis.

433. In some crystals the extraordinary ray is more inclined to the axis than the ordinary one, and in others it is less so; the former crystals are said to have a *negative*, the latter a *positive axis* of double refraction. Iceland spar belongs to the former class, also nitrate of soda, tourmaline, the ruby, emerald, and beryl; but rock-crystal, ice, boracite, &c. are of the latter kind. When two faces are artificially formed parallel to the axis, and a ray is incident on one of them in a plane perpendicular to the axis, it is then found that the index of extraordinary refraction is *constant*, whatever be the incidence, and that it is also a *minimum;* this least value is termed the *extraordinary index.* Its value for Iceland spar is 1·483, while that of the ordinary index, constant in all cases in the same crystal, is 1·654, or nearly as 26 to 29.

434. The great difference in the properties of the two rays, compared with common light, can be shown thus:—When two crystals are placed with two of their faces in contact, or merely parallel, and with their principal planes coinciding, each of the two rays in the first is not divided into two rays in the second, as rays of common light would be: they pass

through the second in the same direction as in the first, as if the two crystals were only one. When their principal planes are perpendicular, each ray in the first produces only a single ray in the second, but of an opposite kind; the ordinary ray in the first forming an extraordinary ray in the second, and the extraordinary of the first being an ordinary in the second; but though in this case also there are only two refracted rays in each crystal, yet they are not in the same line, but, on account of the difference of refrangibility of the two rays, form two crooked lines. When the two principal planes are inclined, each of the two rays in the first produces two rays in the second, an ordinary and an extraordinary; but of intensities varying according to the inclination.

435. When a ray incident in a principal plane on a face of the crystal is polarised in the plane of incidence, it produces only one ray, which is the ordinary ray; and if the plane of polarisation of the incident ray coincides with the co-principal plane, it produces an extraordinary ray; but when the plane of polarisation is inclined to the principal plane, two rays are produced, an ordinary and an extraordinary ray. In short, the effects are the same as when an ordinary or extraordinary ray emergent from one crystal is incident on another, as explained in a previous article.

436. In endeavouring to account for the apparently irregular mode of refraction of the extraordinary rays in Iceland spar, Hüygens discovered that if these rays are conceived to be propagated in waves of the form of spheroids (generated by the revolution of an ellipse about an axis coinciding with the optic axis at the point of incidence), instead of in the form of spheres, like the ordinary ray, that all the peculiar phenomena of double refraction can be completely explained. In order to give an idea of this species of wave, let I E (fig. 82) be a principal section of a doubly-refracting crystal; A I, C D, B K parallel rays of an incident pencil in a plane coinciding with the section (the breadth, I P, of the pencil being very much magnified in order to make the figure distinct); and I P a perpendicular on B K; then I C P is the front of the incident wave, considered as *plane* (which it would be if proceeding

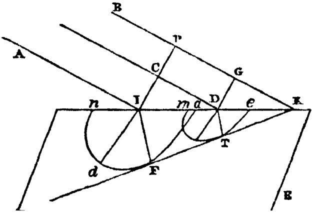

Fig. 82.

from a distant luminary, as the sun) when it has just reached the point I; then while the wave in air passes from P to K, let the spheroidal wave beginning at I from an indefinitely small size expand gradually in magnitude till it reach the position *m* F *d n*, its fixed axis I *d* being in the direction of the optic axis at I; let the spheroidal wave from any other point of incidence, D, expand to the size *a* T *e*, while a wave in air moves from G to K, D G being parallel to I P; then, as in the case of ordinary refraction, the front of the spheroidal wave will be found by drawing from K a tangent K F, or rather a tangent plane to any of the spheroids; then F T K is the required front, and a line, I F, from a point of incidence I to the point of contact F is the direction of the extraordinary ray. The intensity of the light in this front is immensely greater than at any other part of the spheroidal waves. And from all other points between I and K, similar waves are propagated, which all reach the front F K at the same time.

437. Hüygens deduced the following construction, by which the directions of the extraordinary ray in Iceland spar can be determined in all cases: let U I V K (fig. 83) be the refracting surface, and A I an incident ray, the plane of incidence passing through I P the optic axis. With any portion I P of the axis, describe a circle U P O V, and describe an ellipse T P M E S, whose shorter semi-axis is I P, and whose longer semi-axis is to I P as the index of ordinary refraction 1·654 is to that of extraordinary refraction 1·483; then having drawn the ordinarily refracted ray I O by the rule for common refraction, draw the tangent O K to the circle to meet U V produced in K; then from K draw the tangent K E to the ellipse, and join I E, and this is the extraordinary ray. When the incident ray N I is perpendicular to the surface, the point K would be infinitely distant, and the tangent would be M Q, parallel to U V; and therefore I M would be the extraordinary ray, I L being of course the ordinary one. In this case angle M I L is found to be 6° 12′.

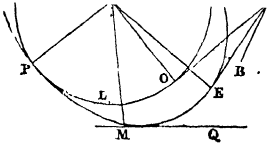

Fig 83

CHROMATIC PHENOMENA FROM INTERFERENCE OF POLARISED LIGHT.

438. Having thus explained the properties of interference and of polarisation in their more simple instances, some of the complex phenomena of this kind may now be mentioned. The most remarkable of these are exhibited by the transmission of polarised light through a doubly-refracting crystal under certain conditions, and the subsequent reflexion of it at the analysing plate; or in place of the analysing plate, a plate of tourmaline may be employed, the ray being *transmitted* through it.

439. When the light is transmitted through a plate of a uniaxal crystal, there are produced by interference beautiful coloured fringes, arranged in concentric circles around the ray that passes perpendicularly through the plate.

440. In order to observe these phenomena in a uniaxal crystal, take a plate of Iceland spar with two artificial parallel faces perpendicular to its axis, and place it between the polarising and analysing plate of the polarising apparatus, or between two plates of tourmaline; and a system of concentric coloured rings will be observed in the form represented in the figure, with a black or white cross, according to the position of the analysing in reference to the polarising plate, formed by two lines passing through the centre, and terminating in a brushy appearance. When the plate of crystal is turned round, there is no change in the rings; or when the analysing plate is turned one or more right angles, there is no change; but if it is turned one, or any odd number of half right angles—that is, 45°, 135°, 225°, or 315°—all the colours are then complementary: in other positions, the figures are varied in colour and form.

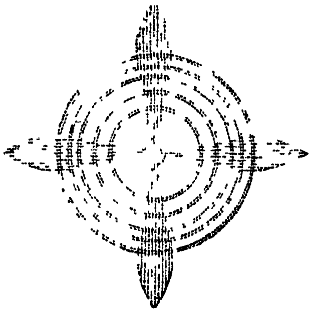

Fig 84

441. When the plate is a biaxal crystal, with two parallel faces formed on it perpendicular to the line bisecting its optic axis, the curves are arrayed around two poles, as shown in the preceding figure.

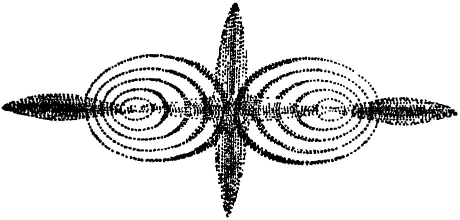

Fig. 85.

NATURAL PHILOSOPHY.

SIXTH TREATISE.

ASTRONOMY.

NOTICE.

THE following Treatise is intended to include a systematic exposition of the appearances and laws of the heavenly bodies, as far as is practicable without the aid of Geometry, Algebra, and the higher Mathematics. The arrangement adopted is what seemed the most natural order of understanding the discoveries of the science, being also the order in which they were made. Some writers commence with the exposition of the form, and magnitude, and true motions of the earth, which is in some respects a natural enough beginning; but in the actual progress of discovery, a full knowledge of the earth came only after an extensive acquaintance had been gained of the heavens, and could not by any possibility have been acquired sooner. The present arrangement has been suggested by the astronomical writings of M. Auguste Comte.

ALEX. BAIN.

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ASTRONOMY.

1. **Astronomy** teaches whatever is known of the heavenly bodies. The earth itself it regards only as one of them; viewing it, not in small portions, as we are accustomed to see it, but as an entire body, such as it would appear were we to behold it from a sufficient distance.

2. The subject may be arranged and treated under the five following heads:—

1st, The **General Appearances** of the Heavens.
2d, The **Means of Accurate Observation**, by the Application of Instruments, and by making Corrections for unavoidable Errors of Observation.
3d, **Geometrical** or **Mathematical Astronomy**; including the Exact Determination of the Numerical and Geometrical Elements of the Heavenly Bodies—that is, their Distances, Shapes, Magnitudes, the Figures they describe in their Motions, &c.
4th, **Mechanical** or **Physical Astronomy**; or the Nature of the Powers or Forces that carry on the Heavenly Motions, the Laws that they Observe, and the Calculation of the Motions from a knowledge of these Laws.
5th, Whatever is ascertained regarding the Universe of the Fixed Stars; this branch is called **Sidereal Astronomy**.

GENERAL APPEARANCES OF THE HEAVENS.

UNIFORM DAILY REVOLUTION OF THE STARRY SPHERE.

3. When we raise our view from the earth beneath and around us, to the sky over our heads, we find it occupied with the sun by day, and the moon and stars by night. The sun

is evidently never at rest, but is either ascending upwards in the sky from the east, or else sinking towards the horizon or sky-line in the west, where his body goes out of sight. The same continual motion of rising and setting is observed in the moon. And when the stars are closely watched for any length of time, it is found that they also are constantly in a movement of the same kind. If, at the beginning of a winter night, we fix our attention on a conspicuous star near the east point of the horizon, and continue to observe it, we shall see it rising higher and higher for about six hours; it will then begin to descend to the west, and in about six hours more it will reach the west point of the horizon, and disappear. If we commence our watch again on the following night, we may discover the same star rising at the east point at about the same hour, and going through its course of mounting, crossing, and descending the sky as before.

4. We have supposed a star that rises in the east to be the one chosen for observation; but in those lying elsewhere, the same continual movement, in one common direction, may in like manner be observed. If we turn to some point between east and north, and notice a star just rising, we find it gradually ascending in the heavens up to a certain point; then descending to the west, and going out of sight; and finally reappearing in the east in about twenty-four hours from the time of its previous rising: but these twenty-four hours, instead of being spent one half above and the other half below the horizon, as in the former case, will be unequally divided between the presence and the absence of the star; more than twelve hours will be taken to pass from the rising to the setting, and less than twelve hours will elapse between the setting and the next rising. The farther *north* the point of rising, the longer the time spent in the upper course, and the shorter the time in the under and unseen course. If we go to the north point itself, and observe a star just a little above the horizon, we will find that it will spend the first twelve hours in ascending to its highest point in the heavens, and the next twelve in descending to the neighbourhood of the horizon; and it will not go beneath at all, but commence again to rise and describe a circle in the heavens as before; such a star, therefore, will be always in sight. In like manner, all stars in the north quarter lying within the circle described by this never-setting star, will perform their daily movement above the horizon.*

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* In the foregoing and in succeeding paragraphs, it is supposed that the stars may be seen day and night. By the naked eye no star can be

5. In the inside of these circling motions we may observe a point in the sky which seems to be their common centre. A star lying in it would be perfectly at rest, and stars near it describe very small circles, or move within narrow limits. This point of rest is situated in the north quarter of the heavens, but more than half-way up from the sky-line, towards the summit. It is called the *north celestial pole*, or the *north pole of the heavens*, and is the most important point in the sky for astronomical references. No visible star is actually residing in it; but a very bright star lies near it, called for that reason the *pole-star*.

6. If, again, we make our observations on stars that rise in the *south-east*, we find that, as with the others, nearly twenty-four hours are occupied between one rising and the next; but that with these, less than twelve hours will be spent above the horizon, and more than twelve beneath it. In ascending the sky, they come sooner to a stand-still, or attain a less height when they begin to descend again. If we turn to near the *south point* itself, we will observe that a star just appears, and then almost immediately disappears, and at the end of twenty-four hours comes into sight again for the same short time. From this we infer that there is a large region of stars performing the common movement wholly out of sight—that, like those we see, they describe daily circles—and that there is a point beneath, which is the centre of those circles, corresponding to the centre of the northern heavens. These inferences are justified by actual observation, as we shall very soon see; and accordingly the centre of the movements of the southern heavens is recognised in astronomy under the name of the *south celestial pole*, or the *south pole of the heavens*. An imaginary line drawn from pole to pole, or from the elevated north resting point to the concealed south resting point, is called the *axis of the heavens*, or the *axis of the world*.

7. If, instead of observing the stars one by one, as we trace their motion through the sky, we fix upon a group of two, three, or four, or upon a cluster, we shall find that, with a very few exceptions, they move in company, and always keep the same distances from one another. This is implied in their going round the sky all in the same time. In fact the

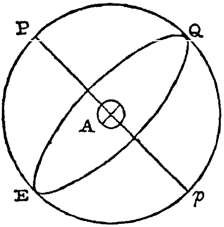
---

seen while the sun is up, but they are all in their places nevertheless. The intense light of the sun generally makes other celestial objects invisible. With good telescopes, however, the stars may be seen in the daytime, in a clear day, except in the sun's immediate neighbourhood. From the bottom of deep wells and mines the stars in the sky overhead are seen through the day. When the moon is at a considerable distance from the sun, it may be seen when the sun is up.

whole starry vault revolves together round the line or axis just mentioned as running from pole to pole; as if the stars were all fixed in a solid shell or hollow ball, turning steadily and slowly round on an axle, and occupying about twenty-four hours in one complete revolution. But owing to one pole being a considerable way up in the sky, and the other far down out of sight, it is evident that this great whirl of the starry sphere goes on in a *slanting* direction: it is not *upright*, for in that case the one pole would be in the very summit of the heavens, and the other directly beneath our feet, and far below the earth; nor is it *horizontal*, like a roller moving on the ground, for in this case one pole would be exactly in the horizon on the north point, and the other in the horizon on the south point; but it has a direction inclined between the two.

8. Next to the poles and the axis of the heavens, we must understand what is meant by the EQUATOR, so called because it is drawn to cut the starry sphere into two equal halves. It is an imaginary plane, drawn right across the axis (or making what is called right angles or equal angles with it), and dividing the whole sphere into two equal half spheres; the one north, or lying round the north pole, the other south, or lying round the south pole. We have thus a *northern hemisphere* of stars, and a *southern hemisphere* of stars. The boundary line between the two, when drawn round the heavens, makes the circle of the equator, or the equal-cutting line.

9. Thus, in the figure, let A be the earth (which is a small object compared with the vast space of the heavens); let P be the north celestial pole, which is always in sight to us; and *p* the south celestial pole, which can never be seen from Great Britain; the line P*p* is the axis of the heavens, slanting, as it actually does, while the starry vault revolves round it; the cross circle EQ, which divides the whole sphere into two equal halves EPQ and E*p*Q, is the equator; and all the stars lying in the upper half EPQ belong to the north hemisphere of stars, whilst all that lie in E*p*Q belong to the south hemisphere of stars.



10. There are many other imaginary points, lines, and circles, which it is convenient to suppose drawn among the stars, and which of course we can actually draw in all our figures or sketches of the stars and the starry sphere, as when we con-

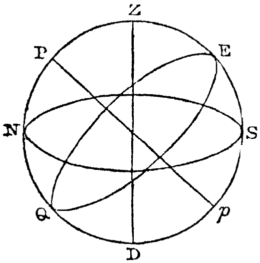
struct maps and globes of the heavens, and in such outlines or diagrams as the one above given.

11. We have already mentioned the *horizon*, or the line where the earth cuts the sky, and separates the upper visible heavens from the nether invisible heavens. If the earth were transparent crystal, we would see the whole starry sphere at once; the under half would appear as we sometimes see the moon and stars in a smooth lake. The south pole and the whole south hemisphere would be seen by standing with our face to the south and looking downwards; just as we see the north pole and the north hemisphere by standing with our face to the north and looking a certain way upwards. But since the earth cannot be seen through, we are always hidden from one half of the sphere; all the stars we can see, or what the earth does not hide, are said to be *above the horizon*, or the sky-line, and all that the earth hides are said to be *beneath the horizon*. The setting of the sun, or the moon, or a star, is its passing beneath this line, or its being concealed by the earth; and the risings of these bodies are their reappearance above this line, or their coming round to the place in the sky where the earth no longer comes between our vision and them.

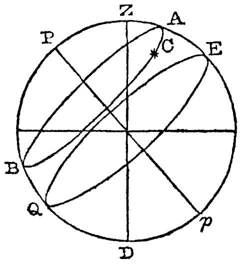
12. The point of the heavens directly over our heads, or the very summit of our sky, is called the *zenith*. It is a sort of pole, or middle point, of the visible half of the heavens. The point that we would see directly beneath our feet, if the earth could be seen through, is called the *nadir*, and forms a pole and a middle point to the nether half of the heavens. These are Arabic words, meaning the extreme up and the extreme down points: just as we would have said, instead of the *zenith*, the *summit;* and instead of the *nadir*, the *bottom* or the *nether* point. While, therefore, the equator makes one division of the stars, into those that cluster and revolve round the upper north pole, and those that cluster and revolve round the nether south pole, the horizon makes a different cut, which is in some degree cross to the other, into the upper visible and the nether invisible. In the divisions made by the equator, the same stars are always in the same hemisphere; in the divisions made by the sky-line, many of the stars are in the upper division one half of the day, and in the lower during the other half. But if the north pole of the heavens were to rise to the very summit or to the zenith, and the opposite south pole descend to the lowest depth or the nadir, so that the axis of the sphere should stand upright, and the great whirl take place in this position, the horizon and the equator would be the same; for the stars of the upper

hemisphere would move round in one level, without ascending or descending, and thus be always in sight, or always above the horizon; and the stars of the south hemisphere would move round in the invisible depths, and be always beneath the horizon.

13. Another artificial circle supposed to be drawn in the heavens, is the *meridian*. Like the equator and the horizon, it divides the starry sphere into two equal half-spheres, but in a different direction from either of those circles. In fact it is so drawn as to be perpendicular to both. It passes through the north point of the horizon, then upward through the north celestial pole, through the zenith, down through the south point of the horizon, through the south celestial pole beneath, and finally through the nadir: so that, in the first place, it lies north and south; and in the second place, it stands upright. Thus, if in the figure P*p* be the great axis of the heavens terminating in the north and south celestial poles, EQ the celestial equator, NS the horizon, and N and S the north and south points of it, Z the zenith, and D the nadir; then the enclosing circle of the figure NPZES*p*DQ is the meridian.



14. While the equator cuts the sphere right across the axis, and makes two hemispheres which always contain the same stars, the meridian cuts it through the poles, so that the axis lies in the plane of the meridian, and the stars in their movement cut it twice in every revolution. It, in fact, divides the *revolution* of the sphere into two equal halves; while a whole day is taken to make an entire revolution, half a day elapses between two crossings of the meridian. Thus a star, C, going round the general axis in the circle ACB, will take a whole day to go from the place C and return to it again; and if we follow it in this course, we will see that exactly one-half of its day will be spent in going between A and B, and the other half in going from B to A; because the meridian divides the circle into two equal halves, and the



star's motion is perfectly uniform. Now, as the meridian lies north and south, the stars, in crossing it, will be either due north or due south, whether they stand low or high in the heavens at the time. Thus the point A, which is the star C's upper meridian passage, is due south; and B, the under meridian passage, is due north.

15. The leading property of the meridian is, that it determines the greatest height and the lowest depth that any star can reach. A star passing the meridian is either at the highest or the lowest point of its course. Thus the point A is the greatest elevation that C attains in the sky, and the point B its greatest depression. The meridian would not have this property, unless it stood upright or perpendicular to the horizon, and also perpendicular to the equator, or to the general direction of the starry movement. Hence when the sun or the moon passes the meridian, or lies due south, we know that it has reached its greatest height, and will immediately commence to descend; if it is a considerable way east of the meridian—that is, if it lies north-east—we know that it is rising, and will continue to rise for some hours; if it is south-west, we may be sure that it is a considerable way down from its greatest height. We know, moreover, that about twelve hours after the sun has passed the meridian above, he is at his very lowest depth, and is passing the meridian below. Hence we can determine the meridian line in the heavens, by observing where a star is when it ceases to ascend and begins to descend; which of course gives us the direction of the north and south points, and serves the same end as the mariner's compass. The meridian also divides the upper and lower course of the stars into equal halves. The middle point between a body's rising and setting is its meridian passage.

THE SUN, MOON, AND PLANETS.

16. Although the general starry sphere turns round in one great mass, so that each star is always in the same situation among the other stars, yet there are a few bodies which are exceptions to the common movement; and these exceptions lead to very remarkable discoveries in the system of the heavens. While the thousands of stars keep their uniform places, there is a small number that, besides going round the sky daily, change their positions among the other stars, and shift about, so as to be sometimes near one, and sometimes near another. These are called *erratic*, or *wandering bodies;* and the general multitude that keep their situations are called the

FIXED STARS, which we use as landmarks whereby to trace the motions of the others.

17. For example, the moon is very soon observed to be an erratic body. Although it goes round the heavens daily—rising, passing the meridian, setting, and again rising in about twenty-four hours—yet if we watch it closely as it lies among the stars, we will find that it is rapidly changing its place among them. One night we see it near one star, and the next night it is at a considerable distance from it; even in a few hours we can notice that it has taken a new position, and placed itself beside a different group of stars. In addition to its daily revolution *with* the heavens, it has a course *through* the heavens. Moreover, the course through the heavens is *contrary* to the general movement; it is as if the moon were, on the whole, moving with the fixed stars, but lagging behind them, so as to lose ground every day; at one hour we may notice it abreast of some conspicuous star, the next hour it will be behind it, by an interval of about its own breadth. If we observe this backward movement for a month on end, we shall find that, in that time, it has gone through a complete circle among the stars, and is at the end of the month nearly where it was at the beginning; and that this is the general law of the movement. In short, the moon, besides its daily course, pursues a *monthly course* through the stars backward, or from west to east, which occupies on an average nearly twenty-seven days and eight hours.

18. Again, the sun is proved to have a motion through the stars, as well as a motion with them. We cannot observe this directly, as in the case of the moon, for the sun's light is so strong that no star can be seen beside it, and therefore we cannot readily observe it changing its place among the stars; but in an indirect way the same thing can be made out.

19. In speaking of the daily course of the stars, we have used the phrase "about 24 hours" to express the time of a complete revolution; as, for example, the time between one crossing of the upper meridian and the next crossing. It is not exactly 24 hours, but somewhat less (accurately it is 23 hours 56 minutes 4·09 seconds). But 24 hours make our day, or the complete circle of light and darkness, which of course depends on the sun; and therefore his daily course round the sky occupies the full 24 hours, while the course of a star is completed in 4 minutes less than the 24 hours. If the sun always kept his place among the stars, his daily period and theirs must be exactly the same; a day of the stars (called a *sidereal day*) would be the same as a day of the sun, or a *solar day*. But since the sun's day is longer than the stars' day,

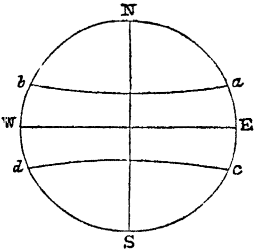
it follows that the sun, like the moon, is constantly falling behind the stars, or is himself describing a backward course among them.

20. The comparison of the sun's day with the sidereal day may easily be made thus:—We can find the length of the sidereal day by watching some star (making sure that it is a fixed one) passing the same point of its course in two successive days. We may note its *rise* one night, and its *rise* the next night; or we may observe two *settings*, or two *meridian passages*, or two passages not on the meridian. Suppose we note a setting, which is the most unmistakeable mark, if we have a clear and cloudless sky-line. If we mark a star setting exactly at midnight, and then observe its next setting, we find that this happens at four minutes before twelve; and on the following night at eight minutes before twelve; the night after about twelve minutes before twelve, and so on; the setting being every night earlier than on the preceding. Three months after the first observation, the star will be found to set about six in the evening; six months after, it will set at noon, and be found rising at midnight; and when a whole year elapses, it will set at midnight again. But midnight marks a uniform point in the sun's daily course—it is the time of his under meridian passage; and between two midnights he has made an exact circle of the sky, while between two midnights a star completes the circle, and goes on a little way farther; so that the stars outstrip the sun, or the sun moves backward among the stars at such a rate that he goes an entire circle among them in the course of a year. The difference of four minutes a night makes a day in the year. During 365 risings of the sun, there will happen 366 risings of any one or all of the fixed stars. Hence it happens that, at different times of the year, the stars rise at different hours of the day and night. If we make ourselves familiar with a *constellation*, or remarkable group of stars, we shall find that if in April they rise at eleven o'clock at night, and remain above the horizon till five in the morning, in December they will not rise till seven in the morning. It is thus that the appearance of the starry sky differs so much at different times of the year, when observed about the same hour in the evening. If we watch the general aspect of the heavens at *ten o'clock* at night on the 1st of September, and see where the various notable constellations are lying, and again observe them two months after, or on the night of the 1st of December, we will find that the appearance is exactly the same at *six o'clock*, and that at ten the whole sphere has rolled round so far as to show a quite different aspect of the sky.

21. After establishing the first peculiarity of the sun's movement among the stars—his yearly movement round the sphere, in opposition to the daily movement of the sphere itself—a second peculiarity of his motion has to be studied, in which also his course differs from that of an ordinary fixed star. A star is found always to rise in the same point of the horizon, to ascend to the same height in the heavens (at least if we remain on the same spot of the earth), and to set at one uniform point towards the west. If a star rises exactly in the east to-night, it will rise in the east every night; or if we find it rising south-east at one period, we may be sure that it will always rise south-east and set south-west, and that so long as we live in one place, its meridian or greatest height will be always the same; also the period of its course above the horizon will be constant and uniform. Neither the different periods of the year (which affect the *times* of rising and setting), nor the lapse of many years, can change the rising points, the meridian heights, and the duration of the upper course of any of the fixed stars. The rising and setting points especially are invariable in all circumstances; but in regard to the sun, these properties are all variable: he does not rise always in the same place in the horizon, nor ascend to the same height in the sky, nor remain up one constant number of hours, even for the same place. What we call *summer*, arises from his spending the larger half of his daily course above the horizon, and ascending at mid-day to a great height in the heavens, in consequence of which he pours out his heat and light for a long period, and with great force; whereas *winter* is owing to his being for only a small part of the twenty-four hours in the upper sky, and being very low even at mid-day. And if we make a set of continued observations on his rising and setting, we shall find that the points of the horizon where they take place are not always the same.

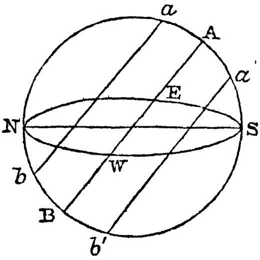
22. If, for example, we commence the observations on the 21st of March (the day known as the *vernal equinox*, when the sun rises at six and sets at six), we find that he rises exactly in the east, and after going round the upper heavens, sets exactly in the west. A few days after, his rise will be not due east, but a little to the north of east; and day after day the rising point will be found approaching more and more to the north of the east point, while the setting point will be just as much north of the *west* point. This shifting will go on steadily for three months, or until the 21st of June, when it will have attained its maximum or greatest amount. On that day (called the longest day of the year, because the sun is

longest up) the rising will be away from the east by about one-fourth of the whole distance between east and north; according to the markings of direction on the mariner's compass, it will be nearly east-north-east, and the setting will be nearly west-north-west. Thus let the circle drawn in the figure represent the horizon, with the four cardinal points marked upon it. On the 21st of March the sun will rise at E and set at W, and he will be situated in the equator; after that day, both the rising and the setting will go gradually to the north side of EW, or the east and west line; and on the 21st of June the rising will take place at *a*, about one-fourth from E, and three-fourths from N, and the setting will take place at *b*. But no sooner is this extreme distance attained, than he commences to retreat; and in a few days after the 21st of June, the rising and setting points will be sensibly nearer to the east and west, and they will go on approaching these points till the 21st of September (called the *autumnal equinox*), on which day the sun will rise, as on the 21st of March, exactly in the east, and set exactly in the west; so that in the six months, including the summer half of the year, he has completed his departure and returned to the east and west rising points, having been *northward*, or in the north hemisphere, in the meantime. Continue the observation still farther, and it now appears that the motion of these points is *south*. A few nights after the 21st of September, he is seen rising a little *south* of east, and setting a little south of west; and he goes on increasing in this direction till the 21st of December (called the shortest day, meaning the shortest daylight), on which day he rises at *c*, as far from E towards the south S as he was towards the north on the 21st of June, the longest day; and the setting point *d* is equally far to the south of W, the west point. By the compass, his rise is nearly east-south-east, and his setting west-south-west. But the 21st of December once passed, he retreats again gradually for three months, and on the 21st of March (the vernal equinox), he is once more found rising in the east and setting in the west; so that in the course of a year the rising and setting points have moved, first to one side, then back again, then onward as far to the other side of the east and west line, and finally have returned to that line a second time. If we



carry on the observations longer, we find that the same course is repeated year after year in exactly the same order.

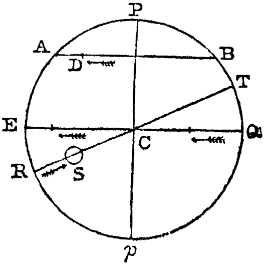
23. It thus appears that a change in the rising and setting points takes place along with the changes in the other particulars—namely, the mid-day height, and the duration of daylight, or of the upper course of the sun; and, in fact, the one is the cause of the other. The great height of the sun in the middle of June, and the length of the midsummer day, depend entirely on the sun's rising in a quarter that is north of the east point; and it is exactly as he changes his place of rising and setting that he rises higher, or not so high, at noon, and stays a longer or a shorter time above the horizon. To understand this, we must first consider that the sun (like the stars generally) in rising moves upward in one constant direction or slant, so long as we stay in the same locality. If we draw a line after him along the sky, that line will have always the same inclination: if it be upright one day (as it is in some countries), it will be upright always; if it be half-way between upright and level (called an angle of 45 degrees), it will always remain so, if we do not travel to another place. The changes of the year make no change in this particular. Thus let NESW represent the horizon, let the letters singly mark the cardinal points, and let SANB be the meridian. If the line AB represent the direction or slant whereby the sun rises and moves through the heavens, when he rises in E, the east point, and sets in W, the west point, he will have exactly the same general direction when he rises and sets south or north of these points. Thus, at the height of summer, when he moves in *ab*, or to the north, the course will preserve the same inclination; hence it is obvious that it will cut the meridian at *a*, or as much higher up than A as the rising point is distant from E; at the same time the upper half of the circle will evidently be the largest half, or the sun will be above the horizon longer than beneath it. On the other hand, in midwinter, when he rises south of east, and has his daily course up and down along *a′ b′* (the edge, as it were, of the circle), he will cut the meridian at *a′*, as much below A, the height at the equinoxes, as *a* is above it, or as the rising and setting points are south of the east and west; and the smallest half of the circle will be above the horizon, or the daylight will



be shorter than the night. The difference between *a*, the midsummer greatest height, and *a′*, the greatest height at midwinter, is twice the extreme divergence of the rising and setting from east and west, or about half of one of the quarters of a circle. If each quarter of a circle be divided into 90 parts (the whole circle having 360, or nearly as many as there are days in the year), each part is called a *degree*, and each degree is subdivided, like an hour, into sixty parts, called *minutes;* then the exact divergence of the risings and settings of the sun in each side of the middle line (which we stated roughly at the fourth of the quarter of the circle) will be 23 degrees 28 minutes, omitting smaller fractions; and 46 degrees 56 minutes will be the difference between the midwinter and midsummer meridian height of the sun. Thus the midwinter height of the noonday sun at London is about 15 degrees, or one-sixth up the sky; the midsummer height will therefore be found by adding nearly 47 degrees, which makes it 62 degrees, or about two-thirds up the sky; the whole distance from the horizon to the zenith overhead being a quarter of a circle, or 90 degrees.

24. There are thus two remarkable deviations in the career of the sun, from the uniformity that prevails among the fixed stars, and both of these deviations occupying a year—two different motions independent of the daily motion of the sphere; the one *backward* among the stars, the other *sideways* among them; and both happening together, and performing their period together. In fact, the two different effects—the falling behind the stars, and the passage into the north and south hemispheres in turn—may arise from one and the same motion; namely, an annual motion backwards among the stars, and in a different direction from theirs—an oblique or slanting course, cutting the equator, and extending into both hemispheres.

25. Let P and *p* represent the celestial poles, round which the starry sphere turns, and let EQ be the celestial equator; then the daily motion of any star is in the direction of the equator, or parallel to it, and never deviates to one side or the other. If a star lie on the equator EQ, it will move round constantly in the equator; if it lie in any other place, as D, it will move round in the circle BDA, in the same direction as the equator, or



parallel to it. But the sun lies half the year in one side of the equator, and half the year in the other side, and on two occasions is exactly on the equator. Now this can be accounted for by supposing that he moves through the heavens once a year (besides moving round with the sphere daily), in the circle RST, running across the equator, and lying with a slant to it of about a quarter of a right angle. Twice a year he will be at C on the equator, and will then rise in the east and set in the west, constituting the days of the equinoxes. Three months from each equinox he will be at his extreme distances from the equator, as at R and T, when he will rise and set farthest from the east and west points, and cause us to have midsummer or midwinter as already explained. (Par. 22.)

26. The annual path of the sun, as thus traced, makes a new great circle in the heavens, of great importance in astronomy; it is called the ECLIPTIC, and the angle that it makes with the equator (23 degrees 28 minutes) is called the *obliquity of the ecliptic.* This obliquity of the sun's annual motion introduces a new complexity into the whole consideration of the heavenly motions; but without it, we should have no variation of SEASONS, or no summer and winter. If the sun were always on the equator, we should have eternal equinox, and the heat of all days nearly the same. If he were always at T, or at his extreme distance from the equator in the northern hemisphere, we should have a constancy of midsummer days both in the length and in the heat, which would completely alter vegetable, animal, and human life. It is because the sun is a *wandering*, and not a *fixed* body, like the greater number of the stars, that every part of the earth experiences the salutary changes of the different periods of the year; and it is the amount of the *obliquity of the ecliptic*, or the distance that the sun passes into each hemisphere, that makes the difference between summer and winter. His summer height being greater than his winter height by exactly twice this obliquity, if the obliquity were greater, this difference would also be greater. If the obliquity were about 40 degrees (nearly half a right angle), the midsummer sun of London would be in the very zenith, and would give to Britain what is called a tropical summer, or a time of overpowering heat and luxuriant vegetation; but on the other hand, his midwinter height would be very small, the December days would only have two or three hours of daylight, and the cold would be nearly as severe as in Greenland.

27. Besides the moon and sun, there are several other wandering bodies, which appear to the eye like stars. The ancients discovered five of these wandering stars, which they

called *planets*, from the Greek word "to wander;" but when the telescope was invented two centuries ago, a vast number of new stars came into view all over the heavens, which the naked eye could never have discovered; and although the great mass of these new bodies are fixed like the rest, additional wanderers came also to be discerned. Such of them as have motions of the same kind as the early known ones, are called *primary* planets; and the earth resembles them in so many respects, that it ranks as one of them. There are now eight independent primary planets, together with a group of at least forty small bodies, so connected that they may be considered as making only one. Another class of the unsettled bodies are called *satellites*, or moons, because they resemble the moon in the same way that the planets resemble the earth, and the number of them at present known is, with the moon, at least twenty. A third class, the most irregular and extraordinary of all, are the *comets*, which appear for short intervals, sometimes in strange shapes, and with a strong glare of light, and then become unseen for many years. The number of these cannot be told—they may, for anything we know, amount to tens of thousands.

28. The primary planets, the least irregular of all the wandering stars, are yet very irregular compared with the sun and moon. Let us take, for example, *Venus*, the brightest of them all, known as the morning and evening star, because its appearances are either shortly before sunrise or shortly after sunset. Like the moon and the sun, it goes the daily round with the great starry sphere, rising in the eastern quarter, going across the sky, and setting in some westerly point; but if we observe it for a number of successive nights, we find that it is constantly shifting its place among the stars. If we watch it for many months, to see if it has a regular course in its shiftings, we find that it seems always to remain in the neighbourhood of the sun; but it does not go steadily through the stars with the sun, but moves backwards and forwards, so as sometimes to be on one side of him, sometimes on the other. Suppose, for example, we commence our observations when Venus is a morning star—that is, rises before the sun in the morning, and when she is distant from him by the greatest interval that she ever has—then, by watching day after day, we find that she is getting nearer to the sun, and delays her rising more and more, till she becomes so close to him, as not to be seen for the strength of his rays. For a number of days she is invisible, and her next appearance is as an evening star, just showing itself in the west after the sun sets, and going down immediately; but as the days pass on, she is found farther up

at sunset, so as to be longer visible; and she continues increasing in this respect till she has attained her greatest distance (which is about half a right angle, but is not always the same), and then she commences to draw near again to the great luminary, going in to him steadily, till she come to set invisible in the very neighbourhood of his rays. She is then occupied in crossing near his body, and in passing a-head of him as far as rising and setting goes; and in a short time she appears in the morning just before he rises, but every day becoming earlier and earlier, till a certain extreme distance is reached, when she commences again to move inwards; so that the course of Venus, in reference to the sun, is regular and simple, being a steady movement backwards and forwards, so as to be at one time moving before him, and another behind him, and twice in the whole course passing near, over, or behind his own body. The time occupied by the entire movement is 584 days, or about 19 months.

29. But if we compare Venus, not with the sun, which is itself in motion among the stars, but with some of the fixed stars themselves, the irregularity of her movements will seem greater. As she keeps always within a certain distance of the sun, she must follow him in his annual circuit through the heavens from west to east, and from one side of the equator to the other; but while the sun himself moves steadily, and almost uniformly, through the stars, Venus sometimes moves one way among them, and sometimes the opposite way, and sometimes stands still like a fixed star. This arises from her going backwards and forwards in the sun's track. When she is a morning star at her greatest distance (or elongation) from the sun, and rising therefore before him, she is necessarily to the west of him (she having come up from the eastern rising point, and being now a certain way on in the sky towards the west); hence when she begins to move nearer him, she must be moving from west to east: moreover, he himself is getting forward from west to east in his annual course, and as Venus at this stage not only keeps up with him, but actually gets nearer him, she must be moving through the stars faster than himself. At this stage her progress among the stars must be very decided; her rate being made up of the sun's rate, and her own advance upon him. This will continue not only till she has gone in towards the sun, and crossed to the other side, or the east of his body (when, therefore, he is at the western or setting point before her, and leaves her behind as an evening star), but it will go on till her distance in this capacity is at its greatest, or till she turn again to approach his body. Then, in the contrary move-

ment, from extreme distance as an evening star to extreme distance as a morning star, she will be falling behind the sun; and it will depend on the rate of this movement whether she has any movement at all among the stars. If her rate of movement into and behind the sun were exactly equal to the sun's movement among the stars, she would seem at rest among them; or if she moved faster from east to west than the sun moved in his course from west to east, she would be going through the stars in the opposite way from him; so that her day, instead of being equal to a solar day of 24 hours, would be shorter than a sidereal day of 23 hours 56 minutes. It happens, in fact, during this portion of the course of Venus, that her speed is sometimes greater than that of the sun in his—in which case she has an actual movement through the stars opposite to his; and sometimes it is less than the steady solar movement—in which case she moves in his direction, but much slower; and again there are times when the two opposite motions are equal, and when Venus stands still among the stars, while the sun goes on leaving her behind. All motion through the stars from west to east, as the sun moves, is called *direct;* the opposite motion is called *retrograde;* and at the times when no movement is visible, the body is said to be *stationary.* It must never be forgotten that the annual career of the sun in the ecliptic, here styled *direct,* is the opposite of the daily rising and setting motion of sun, moon, and stars.

30. The planet called *Mercury* has the same character of movement as Venus, with this difference, that she never goes so far from the sun on either side of him, and performs her sweep backwards and forwards in a much shorter time. The period between her extreme distance as an evening star, and her return to the same, is only 116 days on an average. So close does she keep to the sun, that she is rarely so far out of his blaze as to be seen at all by the naked eye. When traced among the fixed stars, Mercury shows the same peculiarities of being on the whole *direct* in its motion, but sometimes *retrograde*, and sometimes *stationary.*

31. Mercury and Venus, although they pass near the body of the sun in every one of their sweeps backward and forward, very rarely come upon the body itself: they usually pass a little to one side or the other of him. On some occasions, however, at very long intervals, they are seen as a black spot crossing his body, showing that they sometimes pass in front of him. These passages are called *transits of Mercury*, or *transits of Venus,* and come to have a very peculiar importance in astronomy, especially the latter, which occur about twice in 120 years.

32. The other three visible planets—Mars, Jupiter, and Saturn—differ from the two now described, in not being confined to the neighbourhood of the sun: they may be found traversing the whole circle of the heavens, independent of the sun's motion. We have thus greater facilities for tracing their course among the stars, they being very rarely lost among the sun's rays.

33. Taking, then, as an example, *Jupiter*, the most brilliant of three (and with the exception of Mercury and Venus, the most brilliant star in the heavens), and watching him for a series of nights, we find, as in the case of the moon and the sun, that he has a motion through the stars from west to east, or *direct*, but very slow compared with these; so slow, that his motion in a whole year may not be equal to a month's motion of the sun, or three days' motion of the moon. Moreover, if our observations are very close, we discover that he too has the planetary peculiarity of sometimes retreating for a little, standing still, and then commencing to go forward again in his general course. On the whole, he circulates round the heavens from west to east, like the other bodies; but every now and then, and at intervals not very regular, he stands stationary, goes back a little, remains stationary again, and finally goes forward.

34. The planet *Mars*, known by his fiery red colour, has the very same motion as Jupiter, but much quicker. Jupiter takes about twelve years to go round the heavens, Mars only about two years; but Mars has the same irregular tendency to halt, retreat a little, halt again, and then return to its forward march from west to east.

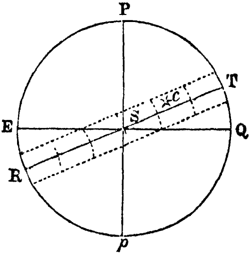
35. *Saturn* is still slower in its movement than Jupiter, and takes about thirty years to go round the heavens. Its motion is also steadier; for although subject to the same irregularities of occasionally halting and retreating, the retreat is much shorter than with the other two, and especially shorter than in the case of Mars.

36. The minor planets discovered by the telescope are all of the character of Mars, Jupiter, and Saturn; not one of them remains in the neighbourhood of the sun, like Mercury and Venus. They have the same general course through the stars, and the same interruptions, although in different times.

37. If we come now to inquire in which circle of the heavens the planets move, whether in the equator, and in the direction of the starry movement, or cross to it, like the sun in the ecliptic, we find the latter to be the case. Although they are all in the equatorial, and not in the polar regions of the stars, they do not remain in the same course, but shift laterally,

and are found sometimes in the north hemisphere, and sometimes in the south; so that if we describe a circle for each of them through the stars, we find that it is just another ecliptic, or slanting circle, cutting the equator. This is found out by the same observations as those that were applied to the sun; namely, by noticing their points of rising and setting through the whole course of one of their circles in the heavens. But on actually drawing these circles, we find that they are almost all very near to the sun's circle, or the ecliptic. Of the five visible planets, Mercury goes farthest out of the ecliptic; but even it does not depart above a third of the obliquity of the ecliptic itself, and the other four are almost close upon the ecliptic.

38. In consequence of this coincidence, astronomers have marked out a belt in the heavens, extending a little way on each side of the sun's course, so as to contain the courses of the planets; this belt is named the ZODIAC. On globes, it is marked by twelve imaginary figures, which the starry groups in the different places of it are supposed to be like; such as, *Aries*, a ram; *Taurus*, a bull; *Gemini*, the twins, &c.; going round the whole course of the ecliptic, and each group extending over a twelfth part of the circle, or over a month's motion of the sun. The sun, the planets, or the moon (which also moves near the ecliptic, and not on the equator), may then have their places pointed out by telling what figure or group, or, as it is called, what *sign* they are in.*



39. Thus in the figure, let P and *p* be the celestial poles, EQ the equator seen edgeways, and RT the ecliptic, or the sun's course, which cuts it. Then if a breadth of about 18 degrees is marked out, half on one side, half on the other side of the ecliptic, the planets will almost always be found within that belt. If the belt all round be subdivided into twelve divisions, each is called a *sign;* and the sun, moon, or a planet may be pointed out by stating that it is in some one of the twelve signs. The signs themselves may be recognised either by the configurations of the stars, as learned from a

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* The twelve signs are—

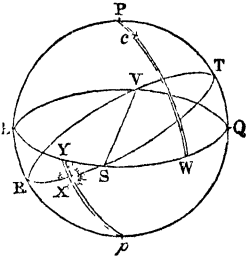
♈ Aries,
♉ Taurus,
♊ Gemini,
♋ Cancer,
♌ Leo,
♍ Virgo,
♎ Libra,
♏ Scorpio,
♐ Sagittarius,
♑ Capricorn,
♒ Aquarius,
♓ Pisces.

celestial globe or map, or by their relation to the sun's place on the days of equinox (21st of March and 21st of September), which place is a great starting point in the heavens. On these days the sun is on the equator, as at S, or midway from pole to pole of the heavens; so that in the figure he lies at the crossing of the two circles—the ecliptic and the equator. This crossing is used to count distance from in an east or west direction, as the poles are used to count from in a north and south direction. The two crossings at opposite sides of the heavens are named after the equinoxes produced by the sun lying in either of them: they are called the *equinoctial points;* and the one where the sun is at the *March* equinox, is the great point that east and west distances are measured from. This point anciently coincided with the commencement of the constellation *Aries*, but it is found to shift slowly in the course of ages, and now it is a whole sign behind, or at the beginning of the constellation *Pisces*, the last of the twelve, which ends where Aries begins. In other words, the sun two thousand years ago lay at the beginning of Aries on the 21st of March; and now he lies at the beginning of Pisces on that day, and does not come into Aries till the 21st of April. But notwithstanding this shifting of the equinoctial crossings, the one that takes place in March is still used to count distances from, and is considered by astronomers the first point of the *sign* Aries; hence the measured places of the fixed stars are, in the east and west direction, constantly changing. A star *c*, which anciently counted 12 degrees from the equinoctial starting point, will be now 42 degrees from that point. This slow change, amounting to a sign, or 30 degrees, in about two thousand years, is called the *precession of the equinoxes.*

40. We must now explain more particularly the system of measuring and stating in numbers the distances and positions of the heavenly bodies, without which we can have no accurate knowledge of their movements. The instruments for taking distances we shall explain afterwards. At present, we consider the manner of counting them.

41. In the figure, let P and *p* be the poles, EQ the celestial equator, RT the ecliptic, which cuts the equator in two opposite points S and V, which are therefore the equinoctial points. Let *c* be a star, whose place it is desirable to fix by stating in numbers how far it is from some known points. A portion of a circle is drawn from the pole through the star on to the equator, so as to cut the equator at right angles (or equal angles). The star's place is then expressed by *two* measure-

ments; one from the pole P*c*, called the *polar distance*, which measurement is an exact north and south measurement; the other is an east and west measurement, and is made between S, the vernal or March equinox, and W, where the circle from the pole cuts the equator: this is called the *right ascension*, being exactly in the direction of the star's daily course. The numbers used are the degrees of a circle. Thus if *c* were one-third of a quarter-circle from P, P*c*, the polar distance would be set down at 30 degrees (marked 30°). And if SW were a tenth part of the whole circle of the equator, the right ascension would be set down as 36 degrees (360 degrees to a complete circle). The number for the polar distance is not so often used as the other part of the circle *c*W, the distance from the equator, which arises from subtracting the former from 90 degrees. Thus, in the present case, *c*W is 60 degrees. This distance from the equator is called *declination*, because the middle line of the sphere is supposed to be a standard line, from which the stars scattered in the hemispheres on each side are supposed to *decline*, or turn away.



42. To take another example:—Let X be the sun, which is always somewhere in the ecliptic. Suppose it to lie in the southern hemisphere, and to be on its way to the vernal or March equinox at S. In this case we draw a circle from the south celestial pole, through X to Y, at right angles to the equator. The arch *p*X is the south polar distance, or YX is the *declination south;* XS is the east and west measurement, or the right ascension, which may be given either by stating the number of degrees in the part of the circle between Y and S, or (for the sake of counting all right ascensions round in one way) by giving the degrees from S round by Q, V, and E to Y. If YS were 40 degrees, the right ascension, counted as before, would be 320 degrees. When the sun is at S, the March equinox, his right ascension is nothing; and being then on the equator, his declination is nothing. On the 21st of June, when he is round to T, his farthest remove from the equator, his right ascension is 90 degrees, or a quarter of his course; his declination QT is then greatest, and is the same as the obliquity of the ecliptic, or 23 degrees 28 minutes (expressed 23° 28′). When he has gone round to the autumnal or September equinox, his right ascension is half a circle, or 180

degrees; but being now on the equator, his declination is again nothing. In midwinter he is at R in the south hemisphere, at a right ascension of three-quarters of a circle, or 270 degrees; his declination ER being equal to the obliquity of the ecliptic, or 23 degrees 28 minutes. The same mode of measurement is applied to the moon and the planets.

APPEARANCES CAUSED BY CHANGING FROM ONE PLACE ON THE EARTH TO ANOTHER.

43. All the previous explanations have supposed that we have been making our observations always in the same locality; and in fact we have spoken of the heavens in a manner chiefly suited to a person residing in Great Britain—many of the foregoing statements would not be true to a person residing in distant countries from our own, as in the Cape of Good Hope, Australia, or Mexico. We must now consider what differences take place in the celestial appearances when we pass from one country to another. It will be convenient to study first the effects of removing north or south, and after that the effects of going east or west.

Appearances caused by moving North or South.

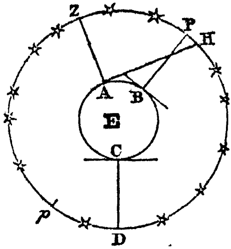
44. If we set out northwards, without at the same time moving east or west, and go on travelling for a considerable distance, and observe nightly the appearances of the stars, the first thing that will strike us will be, that some of those stars whose setting took place far north of the west, or near the very north point itself, now remain up day and night. They ascend, go round the heavens, and descend, as before, but in their lowest point they keep from going beneath the horizon. Their character formerly, or in the place we left, was to remain down out of sight a very short time, and now they have ceased to go down at all; and other stars in the same quarter that still go down, remain down a shorter time than before; so that, on the whole, there seems a general rising of the north side of the heavens: all the circles there are described as at a higher elevation; the meridian passages both above and below are all higher. From this it follows that the pole itself, the centre of all these daily circles, must be *higher up in the sky*. If, again, we turn round and notice the south side of the sky, where we formerly observed stars rising a little east of the south point, ascending a small way, and then descending somewhat to the west of the south point, their whole time above the horizon being very short; if we look for those briefly-seen stars, we find that they do not appear at all: they may be performing

their daily circles as before, but these are now gone entirely through in the nether sphere. The stars that do actually get up a short way still, are those that rose much higher, and stayed up much longer in our former place. It is evident that, on the whole, the south side of the starry sphere has been sinking in the sky, as the north side has been rising. The south celestial pole has dipped deeper into the invisible nether sky, and the north pole risen higher in the upper sky. The axis of the sphere has turned round more near the upright position, and the course of the stars has become more level. The farther north we go, this effect increases more and more. But for the cold and snow of the north countries, we might go northward, finding the north pole of the heavens rising, and the south pole sinking, till the former stood right over our heads in the zenith, and the other right beneath our feet under the earth in the nadir. The sphere would then be spinning upright; the stars would go round the heavens in a perfectly level course, never rising or falling; those that are up at one time, would be up at all times. We would have a constant sight of the north hemisphere of the stars, and never any glimpse of the stars in the south hemisphere. In the summer half of the year, when the sun is in the north hemisphere, he would go round the heavens without setting; and in the other half, from the September to the March equinox, during which period he is in the south side of the equator, he would be constantly invisible, like all the stars in the south hemisphere. In like manner, the moon or a planet would be always above or always below the horizon, according as it was north or south of the equator, which in this case would be the same as the horizon.

45. Although no one has been able to go so far north, on account of the cold (which arises from the sun being half the year out of sight, and the other half moving in a very low level in the sky), so as actually to see this state of things, we are sure that it does occur, from the steady approach to it so far as we can go. It is therefore curious to inquire what is the reason why the mere fact of travelling some hundreds of miles over the earth should so far change the general inclination of the starry sphere.

46. This reason is no other than the *rounding* of the earth, which was probably first discovered from these changes. If the earth were a broad flat, or entirely level surface, such appearances could not arise. Let E represent the ball of the earth floating in the centre of the starry sky; then on any part of its surface, such as A, a line AZ drawn plumb to that place, or perpendicular to it, will rise to Z exactly overhead,

or to the zenith of the sky over the place. Let P be the pole of the heavens, whose height will be PH; H being the distant horizon which bounds the visible heavens seen from A. Let us now travel round to B, and let a line be raised perpendicular to the level of B; this line will proceed to the zenith of the place, which must be in a different direction in the heavens from the zenith of A. In fact, by travelling round the ball, we get a different look-out upon the starry sphere. If B is as far round from A, as P the pole is from Z the zenith of A, then the pole will be in the zenith at B, and all the consequences will arise that were mentioned in the last paragraph. If we were travelling half round the earth to a point such as C, we should face a totally different quarter of the heavens; the south pole and the southern hemisphere would be visible, and the north regions thrown under the earth out of sight. Up and down would come to be reversed: but we must understand that these terms do not mean any one fixed direction in space; they mean only the direction that a stone falls or a plummet hangs, or that we ourselves press the earth. Now all these tendencies are to the *earth's centre*, so that we feel them alike on every side of the earth; on whatever side we are, *up* lies directly over that spot. Z is the highest point up from A; P the highest point up from B; D the highest point up from C.



47. The place on the extreme north of the earth, where the north celestial pole is in the zenith, and the stars move level, is called the *north pole of the earth;* it faces, as it were, the north pole of the heavens. In fact, a line drawn from the earth's centre through this place would terminate in the north *celestial* pole.

48. The roundness of the earth shows itself in like manner when we go *south*, the changes being opposite to the changes above described in the northward course. Having once proceeded a good way south (as to Spain, or to Algiers on the African coast), if we look at the north side of the sky, and compare it with our former experience, we find that stars that went round the heavens without setting, now set and remain below the horizon for a part of their course. The number of those that keep always up is smaller and more contracted towards the pole. The pole itself, the common centre, has sunk very considerably. Again, in the south side

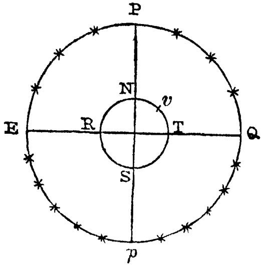
of the heavens, many new stars are found rising; and those that in our former residence rose only a little, now rise a considerable way in the heavens. Moreover, the rise of all bodies is more upright than before, and everything goes to show that the starry sphere has been, as it were, laid more upon its side; the north end of the axis having fallen, and the south end having risen. If we continue our southward journey, we may come to a place where the north pole sinks into the north point of the horizon, and the south pole comes up to the south point of the horizon; the starry axis is then completely on its side, and the stars in their revolution ascend directly upwards, or in a vertical direction, and descend directly downwards. The whole sphere may now be seen in the course of the twenty-four hours; every star rises and sets, and stays half of the day above and the other half beneath the horizon. The stars that are near the poles rise but a short way, from the smallness of their circle; but those that are in the equator, or that rise in the east and set in the west, ascend to the very summit or the zenith. The sun at the equinoxes will therefore be in the zenith at noon, and in the nadir at midnight; his whole course in this situation being direct up and direct down. Hence it happens that in these regions he seems to rise and set more abruptly than in a country like ours, where his motion (like all the other stars) has a very great slant. It is this great elevation that gives his rays such a burning power, as to maintain a far higher heat in those places than in others where he ascends to smaller heights, as, for instance, at the earth's pole, previously described, where his greatest midsummer height is only about a fourth part up the sky.

49. The places where the sphere revolves with its poles in the horizon may actually be reached, and the above phenomena observed. In fact men live where such appearances happen, as in the islands of Sumatra and Borneo in the East Indian seas, in the Guinea coast of Africa, and near the Amazon river in South America. A place of this character is said to be on the *earth's equator*, which is a line drawn round the body of the earth, such that on any part of it these celestial appearances will take place. This line must be a quarter of a circle distant from either pole. (See Map, p. 33.)

50. If we go still farther south than this equatorial line, the axis of the sphere will get up again; but now the south end, or the south pole of the heavens, will mount in the sky, and the north pole descend into the nether unseen regions. We may go on south, this effect increasing more and more, till we become convinced that there is a place in the extreme south end of the earth where the south pole of the heavens would

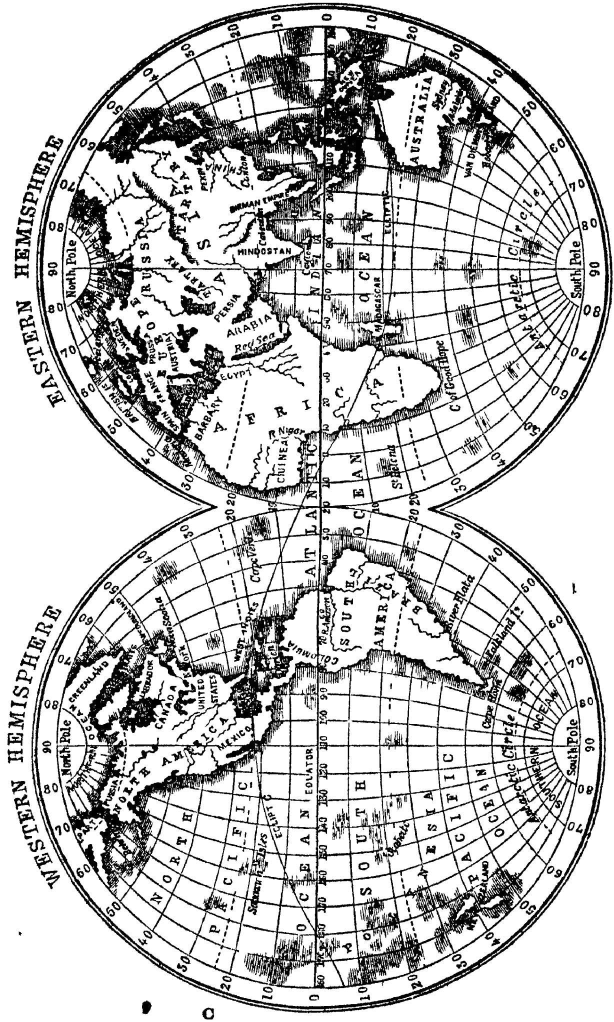
be in the zenith, and the sphere spin upright, as at the far north, only with the other end up. This place is as inaccessible as the other, on account of the cold; but we are sure that it exists, and it is called the *south pole of the earth*, facing as it does the south pole of the heavens.

51. Thus let the inner circle RNTS represent the earth, and the outer circle the starry sphere, revolving around its axis P*p*, P being the north and *p* the south pole, and EQ the equator. The place N on the earth, where the north celestial pole P is overhead, is the north pole of the earth; the place S, where the south celestial pole *p* is overhead, is the south pole of the earth. The circle RT, encompassing the earth in the places where the sphere revolves on its side, is the earth's equator; it is the same plane as the equator of the heavens EQ, and like the latter, it divides the earth into two equal halves or hemispheres; the one (RNT) around the north pole, is the north hemisphere; the other (RST) around the south pole, is the south hemisphere. The line (NS) run through the earth from pole to pole, would be the *axis of the earth*. The equator is right across, or at right angles to this axis.



52. Thus it is that we discover and describe the shape of the entire mass of the earth by what we see in the heavens. We also use these marks, derived from the heavens, to measure distances on the earth. We lay down places on the earth, according to their distances from its equator or poles, in the manner already described with the stars. We can find out how far one place is north or south of another, compared with the whole circle of the earth, by observations of the stars alone. Thus if we set out from a place on the equator at which the poles are in the horizon, to a place where the north pole is half way up the heavens, or at a height of 45 degrees, we are sure that we have gone half way from the equator towards the north pole of the earth. We may not know how many miles we have travelled, but we are sure that we have gone an eighth part of a complete round of the earth; in the above figure, we would have travelled from T to *v*, half way between T and N.

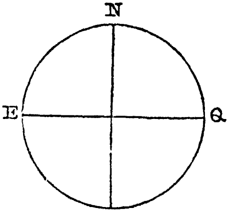
53. To suit this method of determining distances, not by miles, but by proportions of the whole circle of the earth, this


EASTERN HEMISPHERE
WESTERN HEMISPHERE
North Pole
South Pole
EUROPE
RUSSIA
PRUSSIA
AUSTRIA
FRANCE
SPAIN
BRITISH ISLES
TARTARY
ASIA
PERSIA
ARABIA
Red Sea
HINDOSTAN
Calcutta
BIRMAN EMPIRE
CHINA
Canton
EGYPT
BARBARY
AFRICA
R. Niger
GUINEA
C. of Good Hope
St. Helena
MADAGASCAR
INDIAN OCEAN
ATLANTIC OCEAN
AUSTRALIA
Sydney
VAN DIEMEN'S LAND
ECLIPTIC
Antarctic Circle
NORTH AMERICA
CANADA
LABRADOR
GREENLAND
UNITED STATES
MEXICO
Nova Scotia
WEST INDIES
Cape Verd
SOUTH AMERICA
COLOMBIA
R. Amazon
Rio de la Plata
Falkland Is.
Cape Horn
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
Sandwich Isles
Society Isles
NEW ZEALAND
EQUATOR
SOUTHERN OCEAN

circle is divided, like the heavens, into degrees. The quarter circle between the equator and one of the poles is divided into 90 degrees, called degrees of latitude; and every place, according to its relative distance from the equator, is said to have so many degrees of latitude. On the equator itself the latitude is nothing: at the pole it is 90 degrees. On the banks of the river Po in Italy, the north pole of the heavens would be about half way up; hence the ground there would be said to be in latitude 45 degrees. At the Pyramids of Egypt, the pole would be one-third up the northern sky, or have a height of 30 degrees, which is therefore the north latitude of the Pyramids. Near the capital of Norway the pole is two-thirds up the heavens, which proves that locality to have 60 degrees of latitude. In this manner every place on the earth may have a latitude assigned it.

54. If we knew how many miles it takes to go from one degree of latitude to another, we should know how many miles it would take to go round the earth, or we should know the actual size of the whole earth. From measurements made in different countries in the course of the last two hundred years, it turns out that a single degree is between 69 and 70 miles, so that a journey round the whole earth, from pole to pole, would be about 25,000 miles. The greatest length of Great Britain is about 600 miles, which extends only over nine degrees of latitude, or a fortieth part of the circumference of the earth. (See Map, p. 33.)

55. When the lengths of degrees of latitude came to be measured very accurately in various places of the earth, some near the equator, and others near the poles, it was found that a degree near the poles is longer than a degree near the equator. If the earth were of a perfectly round shape, or an exact sphere, all degrees of latitude would be of the same length. Hence it was seen that the earth is not exactly round, but in a very slight degree flattened at the poles, so as to measure shorter from the north to the south pole than from two opposite points of the equator. Thus the length NS between the poles is calculated to be 7899 miles, and the length EQ across the equator 7925½ miles, or greater by 26½ miles. For such an immense body the difference is very trifling; it is, however, not only discernible by fine measurements, but it produces some remarkable consequences.



56. It is by employing in this way, first, observations on the heavens, and next, measurements along the ground, that we survey the whole surface of the earth, and come to know what extent of ground has been allotted to the human family.

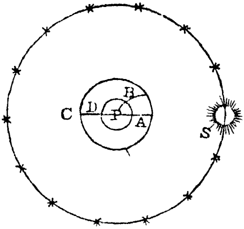
Appearances caused by moving East or West.

57. If the earth were a boundless flat level, our view of the heavens from it would be the same wherever we went. The pole would have the same height in the sky, and the rising and setting of the stars would be unaltered. But we have seen that, by going north or south, such changes occur as prove that our course curves round, instead of being straight. The very same thing happens in going east or west; we find reason to believe that in this journey likewise we go in a round course, as if travelling on the outside of a ball. Both these experiences put together complete the evidence of the rounded form of the earth.

58. If we travel a considerable way due eastward, or without moving either north or south, we find that the elevation of the pole and the inclination of the sphere remain the same; the stars rise to the same height, and continue the same time above the horizon. But if we have carried with us a watch, showing the exact time at the place we left, we find that the risings, settings, and meridian passages of the sun and stars are much *earlier* than before: instead of the sun being at its height at twelve o'clock, it is at its height perhaps at ten o'clock, and all the stars rise and set two hours earlier than we should have found them doing if we had remained in our former place. The farther we journey, this effect increases more and more. If we were to pass from Britain across the continent of Europe, as far as the boundary of Asia at the Ural Mountains, we should find that all the risings, meridian passages, and settings, are four hours earlier than in this country. On the other hand, journeying westward across the Atlantic to America, the contrary happens; the appearances are all later. On the banks of Lake Superior, between Canada and the United States, the sun rises regularly six hours later than in London; three o'clock in the afternoon with us (or three hours after the sun's meridian passage), is nine o'clock in the forenoon there, or three hours before the sun's greatest height. In voyaging westward from America across the Pacific Ocean, we pass a situation about half-way between America and the east coast of Asia, where it is midnight when we have mid-day in this country. To us the sun is highest in the upper sky, when to the voyagers there he is at his greatest depth in the nether sky.

This can arise only from the middle of the Pacific being on the other side of the earth's ball, so as to present its face always to that half or hemisphere of the sky opposite to the one we see.

59. Let the earth be represented in the figure ABC, as if we were looking down on its pole; a direction round it, such as AB, will be an east and west direction. If, then, a spectator at A sees the sun full in sight in his sky, a person at B will see him slanting away, or very much lower in his sky; and round at D he will not be seen at all. To the dwellers at A it will be mid-day; to those at D or C midnight; to those half-way between A and D it will be either six in the morning or six in the evening, according as they are on the one side or the other. The same consequences will happen whether the spectator be near the pole or near the equator; whatever the latitude be, there will be the same discrepancies of time in moving round; only near the pole the distances will be smaller, the whole circle of the earth being there smaller. On the equator the earth is 25,000 miles round; a passage round the earth, in the latitude of the Shetland Islands, would only be one-half of this distance; hence, in disordering the time, 100 miles from the Shetlands would be equal to 200 miles in an equatorial country.



60. Any proportion of a circle of the earth running east and west, or in the same way as the equator (that is, right across the axis which goes between pole and pole), is called so much *longitude*. A whole circle makes 360 degrees of longitude; a quarter of a circle, as from London to Lake Superior, 90 degrees. Every place is distant from another by a certain amount of longitude, if it be at all east or west of that other. If one town is exactly north or south from another town, there is no difference of longitude; there is merely difference of latitude. If one town is exactly west or east from another, there is no difference of latitude; the whole interval is a difference of longitude.

61. To find differences of latitude, we have seen that it is necessary to find the height of the celestial pole in the different places. To find differences of longitude demands a more difficult process; but it is equally a matter of celestial observation. It requires a comparison of the clocks, or reckonings of time, in the different places. Each place has its clocks set

to point to twelve when the sun is in the south point, or meridian passage. Now if a clock that is set for London could be carried to Paris, and remain true in the meantime, and be compared with a Paris clock, the difference, which would be 9 minutes 21½ seconds, is the difference of longitude between London and Paris; or reckoning an hour of time (which is the 24th of a day) at the 24th of the whole circle, or 15 degrees, the longitude in degrees is 2° 22′ 22½″.

62. Since portable time-keepers have been very accurately constructed, they have been used by sailors for finding the longitudes of places at sea. Before leaving Britain, a chronometer is set to Greenwich time, which it keeps wherever it goes; so that if the commander of a ship can find out when the sun is at the meridian in any place, he will have mid-day at that place, and by looking at his chronometer, he will have the time at Greenwich. If this, for example, should be half-past two in the afternoon at his mid-day observation, he is west from Greenwich by 37½ degrees, or nearly a tenth of a circle of the globe.

63. But as the very best chronometers vary in long voyages, and as a small error, even a few seconds, would create an error of many miles in the longitude, a method has been attained of finding the longitude independently of time-keepers, although these are nevertheless used. This method has arisen out of the astonishing perfection of astronomical science, which enables us to predict, for years before, the exact second that some remarkable appearance will happen; such as an eclipse of the sun or moon, or an obscuration of any of the bodies that pass and repass over one another. We can also foresee how far the moon will be from some fixed star every minute and second for several years to come. By the requisite calculations, these distances are found out and published three or four years beforehand in an almanac called the "Nautical Almanac;" and the time reckoned by is Greenwich time, or the clocks of Greenwich Observatory, situated a few miles from London. If, therefore, a seaman measures on any night the distance between the moon and a star (which, from the moon's motion, changes very fast), he can look up the almanac and see what o'clock it is at Greenwich when this exact distance occurred. If he has also found out the time at the place where he is, the difference of the two will be the distance of longitude. If the observing instrument be good, and the observation carefully taken, the longitude may be found in this manner with extreme accuracy.

64. It is thus that celestial observations are used to find the latitudes and longitudes of all places on the earth, and to

lay down on globes and maps the exact situation of all the countries, seas, rivers, and towns in the world; so that we can from thence find their distance in miles, and know in what direction we must go from any one to reach any other.

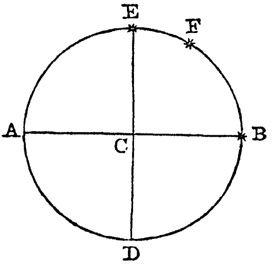
MEANS OF ACCURATE OBSERVATION BY INSTRUMENTS.

65. The great General Appearances that we have explained might have been, and actually were, discovered without much assistance from instruments. The apparatus employed by the astronomers of antiquity was rude and imperfect; and hence they were incapable of noticing very nice movements and changes among the heavenly bodies. But the experience of modern times has shown that, without exceedingly delicate observations, the rules that the stars move by (especially the wandering bodies) could never have been discovered; and we should not have been able to foretell precisely where any star would be at a certain minute in some distant year, so as to work the method above described for finding longitudes. It is this power of accurately foretelling the future, that proves that we know exactly the regular rates of movement of the heavenly bodies.

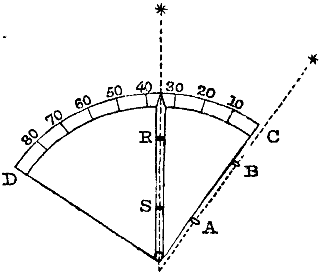
66. Accurate observation has shown that many of the original suppositions as to the celestial motions were incorrect. The uniformity of the daily motion of the starry sphere has been confirmed; but the annual course of the sun among the stars has been proved to be irregular; at one time of the year he moves quicker than at other times. Now, without knowing the irregularities, when there are any, we cannot foresee where a body will be at any after time; nor can we expect to discover the exact influences that are at work upon it.

67. Astronomical observation involves, first, the measurement of the *distances* of the heavenly bodies from one another, and from such standard points and circles as we have already described (the celestial poles, equator, meridian, horizon, &c.); and secondly, the measurement of the *times* that elapse in the course of the movements from one point to another. These distances are not distances in miles (which are an after determination), but distances along the circle of the sky, or *angular* distances, counted in degrees at 360 to the whole circle, or 90 to the quarter circle, which corresponds to a right angle, or the inclination of two lines that are right across one another.

Thus in the circle in the figure, the stars E and B are set down at 90 degrees of distance, if the arch between them be a fourth of the whole circle of the sky, or if the angle at C between them be a right angle; which happens if EC be direct across AB, or if the angle on one side ECB be equal to the angle on the other side ECA. Measurement by parts of a circle and by angles are one and the same thing, and receives the name of *angular measurement*, just as it might also have the name of circular measurement, as it practically is; for the only way that we can know how much two lines are inclined to one another, is to see what portion of an entire circle lies between them.



68. Hence in order to measure such things as a star's distance from another star, a body's height above the horizon, its distance from the pole, its distance from the meridian—we must have instruments that can measure angles, or portions of a circle, round the sky. The simplest shape of such instruments is a plain *quadrant*, with a movable arm, and the round edge cut into equal divisions to represent degrees. Let the edge AC of the board in the figure have two bits of iron (A and B) stuck in it, with small holes in them, so that when a star is seen through those, the side AC is directly pointed towards it; the movable arm RS, terminating in an index over the graduated edge, must also have two sight-holes mounted on it, by which it may be pointed to another star, while AC remains pointed to the first. The end of the arm will then mark off on the divisions of the rim the number of degrees between the two stars, or the angular distance between them.



69. But although this shows the principle of all the apparatus for measuring sky-distances directly, a vast number of refinements are needed to make a sufficient instrument. Immense precautions have to be taken to cut the divisions accu-

rately, to adjust the movable arm, to fix the instrument steadily, to assist the eye in pointing it, and in observing the number of degrees on the rim. Moreover, the changes of the atmosphere (besides introducing other uncertainties into celestial observations) affect the dimensions and position of every material machine whatsoever, so that a quadrant of brass or wood will sometimes show one measure in the morning and another in the evening for the very same distance.

70. The measurement of *time*, the other great element of celestial appearances, was made of old by sun-dials and by the running out of water (on the principle of our sand-glasses), &c.; it is now effected by pendulum clocks, or by watches where a coiled spring serves the purpose of the pendulum, to beat seconds all of the same length; while the wheel-and-pinion-work counts the beats, and shows their number by the hands on the dial-plate.

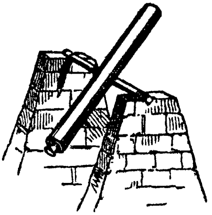
71. The great essential in a time-measurer is to have a uniform motion, such that by measuring off equal spaces we can be sure of equal times. If a snail would crawl along a plank at the uniform speed of three feet in the hour, we could find out the time at any instant by measuring how far on it was; just as a person, knowing that he usually walks four miles an hour, can tell the length of time he has been walking by the milestones. But there is no motion on the earth perfectly equal; the only uniform motion discovered by man is the daily round of the starry sphere. A fixed star seems through all ages to take the very same time between one rising and another, or between one meridian passage and another; and the different portions of the daily circle are described with the same rigorous uniformity. Here, then, we have a perfect standard of the lapse of time; and in order to make use of it, we only require instruments for ascertaining exactly the passages of the stars. The passage used for this purpose is not the rising or setting, but the crossing of the meridian. And with an instrument pointed exactly to the meridian (or to the south or north, as the case may be) the observation is made.

72. By using only a single star, we could determine exactly the lapse of a sidereal day (23 hours 56 minutes nearly); but by using a great number of stars, coming at different times, we could get a great many fixed times in the course of the day; at every hour or half hour (supposing we could always see the stars) we might have exact information of the time.

73. But this method of constantly looking at the heavens to know the hour would be very troublesome, and time-keeping machines are constructed on the earth, which are

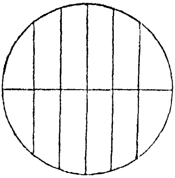
made to go as uniformly as possible, and are kept correct by occasional observations of the passages of the stars. In observatories, clocks are kept whose day is a day of the stars, and not of the sun, called *sidereal clocks;* but for common life, the operations of which depend on the recurrence of daylight, the solar day is used; and for regulating it, we naturally observe the meridian passage of the sun. But this is not uniform, like the passage of a fixed star; hence clocks cannot be kept right by the sun, unless we know to allow for his irregularities. Now-a-days these are well known, and are put down in the almanac; as where it is said, every now and then, that a clock is fast or slow by so many minutes; meaning that the sun is not on the meridian exactly at twelve, but some minutes after or before twelve.

74. Of all motions that we know on the earth, the swing of a pendulum is about the most uniform—that is to say, the time taken up by one vibration is always the same for the same pendulum, whether the vibration make a large or a small sweep. Hence our best and simplest clocks are those that keep a pendulum vibrating, and record the number of its vibrations. There are small inequalities produced by the friction of the machinery, and by the alteration of the length of the pendulum through changes of heat and cold. But the former are done away with by fine workmanship; the latter by methods of compensation, such that the matter of the pendulum is thrown as much one way as the other, in the case of expansion or contraction. By these refinements, clocks are made that do not vary above a second or two in a year. But on the sea, pendulum clocks cannot be kept; hence the utmost pains have been taken to make fine watches, or *chronometers*, as they are called. These are now made so accurate, as not to vary many seconds in the year. For the purposes of common life, clocks of very ordinary workmanship are sufficient.



75. The instrument for observing the meridian passages of the heavenly bodies is called a *transit instrument.* It consists of a tube fitted up with lenses, so as to make it a telescope, having a cross axle resting on two firm stone supports, upon which it can swing up and down. The tube must point exactly north and south, or towards the meridian circle of the sky; and the axis must be very accurately across it, or point east and west, and at the same time be exactly level, and its

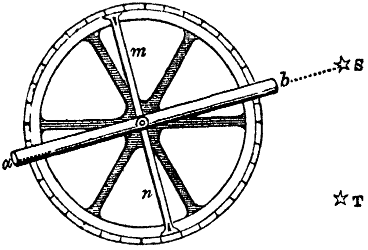
ends ground perfectly round, and equal to one another—that is to say, everything must be done to keep the tube from swaying out of the north and south line when it is moved up and down on its axis. One of the rests of the axis is made movable by screws, in order to give the means of making a perfect adjustment. It is rendered true by setting up at a distance some mark exactly in the south, and putting it right by this mark before an observation is begun. To mark with the utmost nicety the meridian line, there is put across the inside of the tube, in the focus of the eyepiece, a set of wires, five at equal distances up and down, and one across the middle of these. These wires are so adjusted, that when the telescope is set north and south, the middle upright wire lies exactly in the meridian circle; and the crossing of the meridian by a star, or by either edge of the sun or moon, takes place at the instant that the star is seen passing this middle wire; at this moment the time by the clock is noted, and the observation of the transit thus completed. But for the sake of greater certainty, the time is observed of crossing each of the five wires, and the middle instant determined by an average, instead of the middle passage alone.



76. By the transit instrument and sidereal clock, one class of angular measurements can be made independently of a graduated circular instrument; these are the measures of right ascension, or intervals round the sphere in the direction of the daily motion, or of the celestial equator; for as the sphere revolves uniformly, the time between one star's crossing the meridian and the crossing of a second, will show how far the one is from the other in a circle parallel to the equator. Thus if the moon passes the south at six o'clock, and Jupiter at ten o'clock (by a sidereal clock), the interval of four hours will show a sixth part of a circle between them, or 60 degrees of right ascension; and if the sidereal clock point exactly at 0^h, or begin its round when the vernal equinoctial point is in the meridian, the time of passing of each star will be exactly the right ascension of that star: hence in observatories, the taking of the transits of the heavenly bodies is one great part of the business of celestial observation.

77. There is no other angular measurement that can be effected without graduated instruments. To find the other great element of a star's position—its distance from the celestial pole, or its distance from the celestial equator, called the *declination* (one measurement sufficing for both)—a circle, or

portion of a circle, with a divided circumference, is necessary. The instrument commonly used is that called the *mural circle*, because it requires to be firmly fixed in a massive stone wall. It is a brass wheel, with one side of the rim accurately cut into subdivisions for degrees; and a telescope like the transit tube, mounted on the same axle, and moving round it. Thus let there be a circle, with its marks for degrees. In the centre a hole is pierced, and an axle inserted carrying the tube *ab*, across which lie two arms *mn*, making one piece with the tube, and serving as indices to point to the divisions of the rim. Then if this apparatus be mounted, like the transit instrument, so as to point north and south, it will observe the transits, and at the same time measure the distances of the stars from the pole, or from one another in respect of polar distance. Thus suppose the telescope is pointed to the object S; by means of clamps, the circle and the telescope are rigidly fastened in that position; the pointing of the index is then noted, and the degrees and fraction of a degree written down. The circle being still kept fast, the tube is unclamped, and turned round to another object T, and adjusted till T is seen at the crossing of the middle wires; it is then clamped, and the pointing of the index arm is again read in degrees and parts of a degree. The one number is then subtracted from the other, and the difference is the angular interval between S and T. Hence if S were the celestial pole, the degrees between it and T would be the polar distance of T. If, in this case, the number on the rim between the two places were 50 degrees, this would be the star's polar distance, and 40 degrees would be its declination or distance from the equator. By this compound instrument, therefore, along with the clock, right ascensions and declinations can be observed together, and the place of the body in the heavens fixed by a single observation.



78. Angular measurements of every kind are made with instruments on the same principle, containing a metallic circle or portion of a circle (often a fourth, or a quadrant) accurately divided on the rim, and carrying a telescope and an index arm. The accuracy of observations by such instru-

ments must depend, 1*st*, on the exact pointing of the tube to the object; 2*d*, on the accuracy of the markings of the degrees, each one of these requiring to be exactly a 360th part of a whole circumference; 3*d*, on the nicety of the means of finding the exact fraction of a degree, when the index points between two of the marks on the rim. Now, in the first place, for pointing the tube truly, it is made a telescope, as already described, and furnished with cross wires or threads, to give the very point where the star should lie. As to the second thing, or the graduation of the limb, it is a matter of workmanship, and has attained a very high degree of perfection. In the third place, for reading off the *limb* (as the divided side of the rim is called), and for finding the exact subdivision of a degree down to minutes and seconds, the index terminates in a compound microscope, with cross threads in its focus, whose intersection is, as it were, the point of the index. If this intersection do not cover a degree-mark on the limb, but lie between two, a connecting screw is turned round, which brings the crossing up to the nearest line; the turnings and fractions of a turning are then counted; and from the number of these the exact subdivision is attained. Thus suppose the cross threads were seen to lie between the 72d and 73d degree-mark, and suppose that the screw moving the index were so fine that 120 turns were requisite to move from one degree to another; then let the index be screwed back till the magnified cross threads are seen exactly over the line of the 72d degree; and if, on counting the turns, we find 38⅓ turns requisite for this, it will follow that the point will be 17 minutes and 10 seconds beyond 72 degrees—that is, the reading will be 72° 17′ 10″. Another ingenious contrivance for the same end is the *vernier scale.*

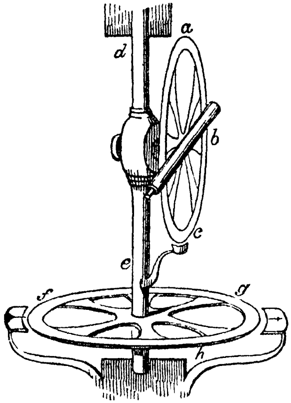
79. In working the mural circle to find declinations and polar distances, it is necessary to determine with the greatest precision the place of the celestial pole. If the pole were occupied by a central star, the matter would be easy; but as it is really a vacant spot, it can only be determined by seeking the exact centre of the daily circles of the stars. In determining this, the first thing sought is the exact meridian circle, which must be found before the transit instrument is applied to furnish right ascensions. The meridian is determined by the highest and lowest passages of the stars; and it is made sure by finding that the time between the upper and lower transit, under all circumstances, is precisely half a sidereal day. The pole itself is exactly the middle point between the highest and lowest passage of a star; if, therefore, a star be chosen near the pole, and its height marked at the upper

transit, and then at the lower, the middle height between the two is the height of the pole; and the difference between the height of the pole thus fixed, and the height of any star at its meridian passage, gives the polar distance of that star. Thus suppose a star passes the meridian 25 degrees below the pole, 25 degrees is its polar distance, or 65 degrees is its declination.

80. It is also necessary to have upon an instrument a mark for the horizontal point, so as to find the exact heights of stars above the horizon, or their exact distances from the zenith. We have already seen that it is the height of the pole above the horizon that gives the latitude of a place on the earth, and that the efficacy of the sun depends on his extreme or meridian height; and there are many other reasons why heights should be measured. But the sky-line is not the exact horizontal line; it does not perfectly divide the whole sphere into two equal halves, the one seen above, and the other concealed below. It is sometimes contorted by mountains and uneven ground; but even in the middle of the ocean the visible horizon does not exactly halve the sphere, if our eye is raised above the surface of the water. Instead, therefore, of measuring the height of bodies above the visible sky-line, artificial horizons are made by the help of the plumb-line or the fluid level; and at sea, where the visible horizon must be used, a correction is always made, corresponding to the height of the observer's eye above the level of the water. This correction is termed the *dip*, or depression of the horizon.

81. Compound instruments are formed to measure other quantities besides the declination and right ascension. Thus we may have an instrument that shall measure height above the horizon, together with *bearing*, or direction in reference to the cardinal points; this last quantity is called the *azimuth*. It is measured from the north or south points; in our hemisphere it is measured from the north point, or from the upright arc that the pole lies in. Thus if a star were north-west in the heavens, it would have 45 degrees of azimuth. An instrument for measuring azimuth along with height requires to combine two graduated circles; the one upright, the other horizontal. Thus let *abc* be an upright circle with a tube attached, as in the *mural circle*, then this circle is fixed into the side of an upright bar *de*, and this bar goes into the centre of a second graduated circle *fgh* lying flat, and turning with the upright bar. To point the telescope on the upper circle to any star, both circles will require to be moved—the upper circle in order to get the proper height, and the under

circle to get the proper bearing or azimuth; and the degrees indicated in the one case will show the height, and in the other case the azimuth; supposing the horizontal point to be marked on the first circle, and the north point marked on the second.



82. If, instead of being placed upright, to give altitudes and azimuths, the axis of this instrument be pointed to the pole, it will give polar distances and right ascensions; and such an instrument, called in that case an *equatorial*, was in former times used for measuring these quantities: but the transit instrument, with its single circle, and the sidereal clock, are now used for this purpose; being much more accurate and certain, and more easy to manage.

83. A very important instrument for measuring celestial distances is that called *Hadley's Quadrant*, or *Sextant*. It is the only instrument found workable at sea; hence it is exclusively used in nautical observations. Its principle is to make one of the two bodies appear, by reflection from a mirror, to lie close to the other, as seen directly; and when the instrument is so adjusted, by moving the index arm (which carries the mirror), that the two stars seem exactly to touch each other, the place of the index shows the degrees of actual distance between them. By this the distances of the sun and moon are taken from one another, from the stars, and from the sea-line or horizon.

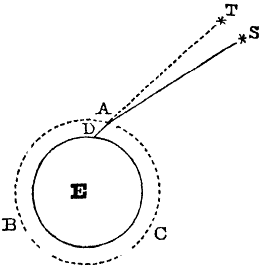
CORRECTIONS TO BE APPLIED TO ASTRONOMICAL OBSERVATIONS.

84. After obtaining the most perfect instruments for measuring time on the one hand, and circular or angular distances on the other, it is found that observations are still inaccurate, owing to the appearances of the bodies themselves being so distorted, as to make them seem out of their real places. One cause of this alteration of apparent place is the atmosphere, which bends the rays of light as they pass through it, and makes us suppose a star to lie in a different position from the reality. This effect is called *refraction*.

Refraction.

85. It is a general law of the movement of light, that in passing into a transparent mass, like water or crystal, it is bent, and moves within the mass in a different direction from what it had before entering. Even the thin air of our atmosphere has this effect upon the light of the sun, moon, and stars: the rays of these bodies move in a different course within the atmosphere from what they had before reaching it. Now, as we can judge of the place of a body only by the direction that we see it in, if the direction of its light be changed while it remains, we will have no means of knowing where it really is. If we saw the sun only from a pool of water, we should suppose that it lay in the depths of the earth.

86. The particular effect of the atmosphere on the light of the heavenly bodies is the following:—Let **E** be the earth, and ABC the outline of the atmosphere; a ray of light coming from a star S, on reaching the outer surface of the air, is bent downwards in the direction AD, and on striking the earth, it has the effect of having come straight from T, and to the observer it really gives the impression that the star is at T, or at a higher point in the heavens than S: so that in fact all the stars and luminaries seem higher up than they really are; excepting of course those that are in the very summit or the zenith, which cannot be made higher. It is necessary, therefore, to find out how much a star is displaced in this way, that the change may be subtracted from the apparent height to give the true height. Now it is known, from the general laws of light, that this bending and displacement are greatest at low heights (greatest of all at the horizon), and diminish gradually up to the zenith, where they come to nothing. Hence a table has to be formed, telling how much the refraction is for every degree of height from the horizon to the zenith.



87. These refractions can be obtained only in an indirect way. For example, a star is fixed upon such that in its upper meridian passage it passes through the zenith. In this position it is not affected by refraction, and its true polar distance can be known. Then, by *calculation*, it can be found what its

true height is at any other part of its course, when it has descended from the zenith; and by *observation*, its apparent height is also known, which will be so much greater than the true height, as obtained by the calculation. The true height, subtracted from the observed height, will give the exact amount of the atmospheric bending or refraction. In this way astronomers have determined the refractions for all degrees of height. But it is found that the effect of the atmosphere fluctuates very much, according to the place, the seasons, and the weather; hence no one table of refractions will be always true. To obviate this, each observatory has to calculate refractions for itself, and to allow for fluctuations, by correcting the average quantity according to the thermometer and barometer at the time of observation. Every measurement made in the sky, except that of bearing or azimuth, must be affected by refraction.

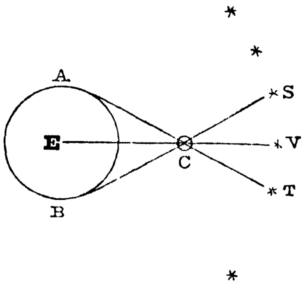
88. The actual amount of the refraction at the horizon is above half a degree, which is about the breadth of the sun or moon. Hence either of these luminaries is wholly above the horizon to the sight, when in reality it is wholly beneath. Refraction causes each to rise two minutes earlier, and set two minutes later, than if the rays came straight to the earth. As a body ascends the sky, the refraction diminishes rapidly. At 10 degrees of height, it is only about the twelfth of a degree, or a sixth of the amount at the horizon. Half-way up, or at 45 degrees of height, it sinks to 1 minute, or the sixtieth of a degree; so that for the upper half of the heavens it is but a small quantity. Astronomers, therefore, prefer taking observations well up in the sky, when it is practicable; for there the whole refraction being small, its fluctuations become almost insignificant.

Parallax.

89. The influence of refraction is the same in amount for all celestial bodies: if a star is found to be bent a certain quantity at some one height, the very same bending will happen to the sun, moon, and all other objects at that height. But the distortion arising from parallax is different upon different bodies: for the fixed stars it is imperceptible; for the moon it is a very large quantity, much greater than refraction; for the sun it is small; and for several of the planets still smaller.

90. Parallax arises from the largeness of the earth; and it is the difference caused by viewing the same body from different sides of the globe. If one observer be situated on one place, and another on a place directly opposite in the other

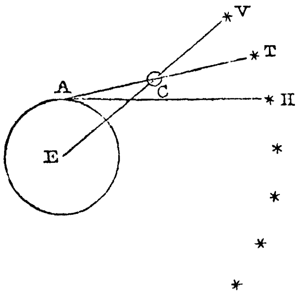
hemisphere, they will be nearly 8000 miles apart; and if both look at the same heavenly body, it ought not to appear to both in exactly the same situation. Thus if **E** be the earth, and A and B two stations in opposite hemispheres, and if the same body C is observed from each, and its place noted among some very far-off bodies, the observer at A will suppose C to lie at T, and the observer at B will suppose it to lie at S; and hence they will disagree about its real position, unless they make allowance for the difference between their stations. In the same way, another observation made between A and B would give a different place to the body C; and in order to prevent the confusion that would thus arise, each observation is corrected so as to give the place of the body as seen from the *earth's centre;* which alone can be reckoned the true place of the body. Thus when the observer at A discovers the object at T, instead of setting that down as the real place, he calculates how much T is below V, the place seen from the centre, and adds this amount to his observed height, and sets down the sum for the true height. The amount of TV thus added is called the *parallax*, It may be represented by an arc in the sky, as TV, or by an angle at the body, as TCV, or the opposite and equal angle ACE.



91. The parallax depends upon the actual distance of a body from the earth; hence it reveals to us the great fact, that the objects in the starry heavens, although the eye supposes them equally far off, are really at very unequal distances. The vast multitude of the fixed stars seem to have the very same position from all sides of the earth, which proves that their distance must be enormous; seeing that two men 8000 miles apart see them in the same places. But the moon is found to have a difference in place equal to four times her own breadth, if seen from opposite sides of the earth. This not only proves her to be nearer than the fixed stars, but it gives us the means of measuring her real distance in miles, as we shall afterwards see.

92. The question of parallax is thus mixed up with the great question of the distances of the heavenly bodies; hence it is not till all the distances are found, and all the changes

which may happen in any of them are discovered, that the real place of a body, as if seen from the earth's centre, can be determined.



93. The influence of parallax is, like refraction, upon the height of bodies; but its effect is in the opposite direction to the effect of refraction. It makes them always *lower* than they would be if seen from the centre of the earth. Thus the line ACT is the direction of C from A on the surface, and ECV the direction from E at the centre, and the apparent height HT is less than the true height HV. Hence in an observation of height, the amount of the parallax, the arc TV, or the angle VCT or ACE, must be *added* to the observed height, *after* the refraction has been subtracted.

94. Like refraction, parallax is greatest at the horizon, and nothing at the zenith; because the line from the surface and the line from the centre coincide, if drawn to the summit of the heavens. But the parallax decreases in a *fixed proportion*, so that if it is once obtained for one height, it can be calculated for every other. Thus if the parallax at the horizon, called the *horizontal parallax*, be discovered, the parallax at all heights can be deduced without any new observations.

95. The same method could be applied to find the parallax that has been already described for the refraction. If a body in its course pass through the zenith, its true place is known without any correction; and from this we can calculate what its true place is a few hours after, when it has descended, and come to be affected by the parallax. If we then observe the apparent place, it will be lower than the true place as calculated, and the difference would give the parallax, supposing we could allow exactly for the refraction. Thus suppose we observed the moon in the zenith, and calculated the time when its lower edge would be one degree from the horizon, if seen from the centre. Then if on clearing away refraction, we find that it appears actually to touch the horizon at the time calculated for, we infer that parallax has depressed it a degree, or that the horizontal parallax of the moon amounts to one degree. But as it so happens that the bodies that show parallax are the wandering bodies in the zodiac, which keep nearly the course of the sun, these bodies cannot be seen

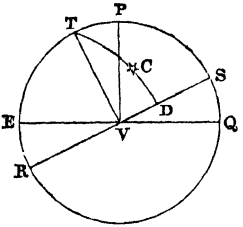
in the zenith, except in the neighbourhood of the earth's equator, or in tropical countries; hence this method could not be followed in European observatories, even if it were an accurate method, which it scarcely is. The methods actually used will be alluded to when we explain the determination of distances.

96. Besides refraction and parallax, there are other corrections necessary to be applied to astronomical observations. There is another kind of parallax in addition to the above, and other causes of distortion; but they are so mixed up with the more advanced discoveries of astronomy, that we shall defer mentioning them for the present.

97. Astronomers are able, by refined instruments, and by knowing all the requisite corrections, to construct a perfect map of the heavens, or to give a catalogue of the stars, with their true places calculated in degrees of declination and right ascension. With regard to the fixed stars, this need only be done once, if it is perfectly done. But the wandering bodies must be perpetually observed, and their places written down for every day, hour, and minute, until it is discovered by what regular law or rule they move, or the precise rate of their motion under all circumstances. If this were once discovered, their places might then be *calculated* for all future times, and observations of them might cease; since the chief thing that we can know about the heavens is, how they will appear, and what will be the places of all the bodies, at any time that we choose to assign. But it turns out that the complication of the movements of some of the wandering bodies is so very great, that the daily observation of them must be carried on for a long time to come, as well as the calculations from the discovered laws of their motion. Catalogues of the stars, and of their exact places, to the number of several thousands, have been formed; and the fixed stars are thus known marks whereby we may trace the courses of the wandering bodies.

98. It is necessary to explain here that the places of the wandering bodies are often reckoned with reference to the ecliptic, or the sun's annual circle. As these bodies move near the ecliptic, it makes, as it were, a more natural line of reference than the equator, which they all cross with considerable obliquity, and depart from to great distances. The distance of a planet, or of the moon, from the ecliptic on either side, is called its *latitude;* its place along the ecliptic, or round the heavens in the same direction as the ecliptic, is called the *longitude*. The longitude is measured from the

vernal equinoctial point, and in the direction of the sun's movement (from west to east), the same as the right ascension. Thus let EQ be the celestial equator seen edgeways, RS the ecliptic cutting it; and let VT be drawn at right or equal angles to the ecliptic, it will terminate in T, the *pole of the ecliptic*, as P is the pole of the equator. Then if C be a planet, its place may be reckoned by latitude and longitude thus:—Draw a circular arch from T through C to the ecliptic; CD in degrees is the latitude, or distance from the ecliptic; and VD is the longitude measured along the ecliptic from the equinoctial intersection of March, or the first point of Aries. At the spring equinox, the sun has no longitude; at midsummer he has a quarter of a circle, or 90 degrees; at the autumnal equinox he has 180 degrees; at the midwinter solstice, 270 degrees. His latitude would be always nothing, were it not that he has a very slight irregularity of motion, owing to which he does not describe a perfect circle in the heavens, but goes now to one side and now to the other; whereas the ecliptic is supposed to be a perfect circle, representing the average path, or running as nearly as possible in the middle of the deviations. These deviations rarely exceed what is called a *second* in circular measurement, or the 3600th of a degree. When the moon or any planet crosses the ecliptic, it of course has no latitude.



99. It is not necessary to make separate observations to find the latitude and longitude of a body; they can be calculated, from the declination and right ascension, by trigonometry, if the obliquity of the ecliptic be accurately known. Or if the latitude and longitude were given, the declination and right ascension could be calculated. Of these four quantities, three are expressed always in degrees (360 to the circle); but the right ascension, which is got immediately from the time of a body's passing the meridian, is expressed in hours, minutes, and seconds; 24 hours to the circle. Thus if the point of the heavens where the ecliptic and equator intersect in the sign Aries, or the vernal equinox, be observed to pass the meridian (which would be $0^h\ 0^m\ 0^s$ on the sidereal clock), and thereafter a planet or star at half-past two on the sidereal clock, the difference in time, 2 hours 30 minutes, would be stated as the right ascension of the body. So 16 hours 15 minutes would be the right ascension of all

stars on the meridian at 16 hours 15 minutes on the same clock; the sidereal reckoning of hours being carried on to 24, instead of making two half days of 12 hours each.

100. Confusion sometimes arises from the use of the words *latitude* and *longitude* in celestial measurements, since they do not mark the same quantities in the celestial sphere that they do in the sphere of the earth. Latitude on the earth means distance from the earth's equator; latitude in the heavens does *not* mean distance from the celestial equator, which is the earth's equator extended to the sky: this distance is expressed by *declination;* and celestial latitude means distance from the ecliptic, which runs in a different direction from the equator of heavens and earth. So longitude on the earth is paralleled by right ascension in the heavens.

101. The reason of this discrepancy is, that the celestial equator is not the most permanent circle of the heavens; it has not the fixed position that the terrestrial equator maintains in the earth; on the contrary, it shifts its place in the course of ages, and divides the starry sphere differently at different periods. The only circle on the heavens that approaches to the *permanency* of the earth's equator is the *ecliptic,* which passes through nearly the same line among the stars at all times; and for this reason the terms latitude and longitude, expressing on the earth invariable measurements, are used to express the least variable of the starry measurements, or measurements by the ecliptic.

102. To avoid the incessant repetition of the term "celestial" before "equator," when speaking of the equator of the heavens, this equator is sometimes called the *equinoctial,* which, without any second word, distinguishes it from the equator of the earth.

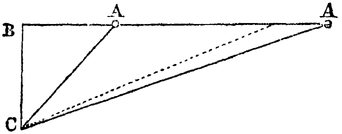
GEOMETRICAL ASTRONOMY.

103. Geometrical or Mathematical Astronomy investigates such elements of the heavenly bodies as their distances, dimensions, and forms, and the figures of the paths that they describe in their movements. In the preliminary sketch of the heavens already given, we have described merely the general and obvious appearances of the starry sphere. But we must now consider how these appearances are connected with distances, with actual dimensions, and also with the position of the earth whereon we stand. The moon is to our

sight a vastly greater object than any of the planets or stars; but it remains to be seen whether this is owing to her being of much greater real bulk, or to her being nearer to us than the others. Again, we cannot help supposing, at first sight, that the earth is at a dead rest in the centre of the universe, and that the heavens have a real whirling motion around it; but when we consider that the earth is a detached ball hanging in free space like one of the heavenly bodies, it is possible that it may be in motion itself, which would very much alter our views of the heavens. This opens a question that must be decided by the observations and reasonings of geometrical astronomy. Geometrical Astronomy also paves the way for Mechanical Astronomy, or the inquiry into the powers or forces that keep up the movements.

DISTANCES OF THE HEAVENLY BODIES.

104. The mutual distances of the heavenly bodies, counted not merely in circular arches of the sky, but in some lineal measure, such as miles, are the very first quantities to be determined. Now it is possible to measure the distance between two objects without travelling from the one to the other. The measurement of inaccessible distances depends upon the change in the direction of a remote object, caused by moving a certain way to one side. Thus suppose a person at B were desirous to find how far A is from him: he would measure off a distance (BC) at right angles to a line from B to A, and at C he would find, by an instrument for taking angles, what is the extent of the angle made by BC and AC. If A were very near, the angle at C would be small; if very far off, it would be great; and the exact amount of the angle fixes the exact distance of A; for one angle will correspond to only one distance. Thus suppose BC were 100 feet, and the angle at B a right angle (or the fourth of a circle of angles), and the angle at C half a right angle, or 45 degrees, then BA would be exactly 100 feet. If C were 60 degrees, BA would be about 175 feet; and for every other measure of C there would be some one fixed and ascertainable distance between A and B. The rules of plane trigonometry are contrived to execute calculations of this sort. When the angle B is a right angle, the angle at A is the difference between B and C. Thus if C were 70 degrees,



then A would be 20 degrees. Now if a certain length, such as BC, be known, and if the angle that it has at some remote point, such as A, be known, the distance of A from B is a determinate quantity which can be calculated.

105. Hence to know the distance of a celestial body from the earth, we must choose two terrestrial stations whose distance we know, and take the angles at each station. Thus to find the distance of the moon, an expedition was arranged between two French astronomers, Lacaille and Lalande—the one to go to the Cape of Good Hope, and the other to Berlin, places very widely apart, and each measured at the same instant of absolute time the place of the moon among the stars. The displacement occasioned by the distance between the two places was thus accurately known; and being about a degree in amount, its measurement could be depended on, as it is possible, on good angular instruments, to measure within about one second ($\frac{1}{3600}$th of a degree) of the truth. Now the distance between the two places is known from the size of the earth and their difference of latitude, and is between 10,000 and 11,000 miles; and the distance corresponding to the angle observed, is about 237,000 miles, or almost sixty times the half diameter or radius of the earth. In the former figure, BC would be, for this case, upwards of 10,000 miles, and the angle at A one degree, and the distance AB 237,000 miles. From the surface of the earth to the surface of the moon is equal to about ten circumnavigations of the earth. Travelling on a railway day and night, at thirty miles an hour, it would take nearly a year to pass over this distance.

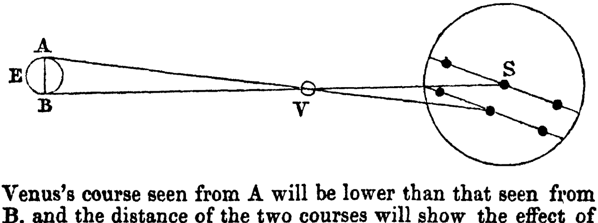
106. By repeating this operation, it would come to be known whether this distance is always the same, or whether the moon is sometimes nearer and sometimes farther from the earth—a thing also essential to be ascertained; but this fact can be determined in a less laborious way, which we shall afterwards point out.

107. When the same device is tried upon the sun, it is found to fail; the difference of the angles at B and C, or the angle A, is so excessively small, that the errors of observation make a large share of it. Instead of a degree, it would be only about the $\frac{1}{400}$th part of a degree, and the possible errors might create an error of one-fourth of the whole distance; in other words, the distance of the sun so immensely surpasses the distance of the moon, that for the same base-line the distant angle is perhaps 400 times less in one case than in the other.

108. A plan was proposed by an ancient astronomer, Aristarchus, for finding the distance of the sun, by comparing it,

not with a distance on the earth, but with the distance already found between the earth and moon, which, being a much larger quantity, the angle to be measured would be larger and less affected by the errors of observation. But this has peculiar difficulties, which make it equally unsafe on the whole. Aristarchus himself (having, however, nothing but the rude instruments of antiquity) made the attempt, but he could find only that the sun was at least 20 times farther off than the moon.

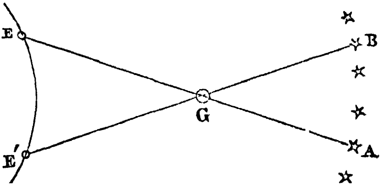
109. The method finally adopted for the distance of the sun, was by observations of a transit of Venus across his body. In the year 1769, one of these transits took place, and expeditions were fitted out by the British, French, Russian, and other governments, to observe it from different sides of the earth. The expedition of Captain Cook to Otaheite was one of them. The line of Venus's passage across the sun being different according to the position of the observer, each observer had to find this line from his own station—that is, to note how far it was from the centre of the sun. Now, as a line near the centre would be much longer than a line near the edge, the easiest way of determining the length was to note the time that Venus took to traverse the sun from each place; this time would give the length of its course upon the face of the sun, and the length would give the distance from the centre. And the thing ultimately sought was, the breadth between the two courses, as seen from opposite sides of the earth; this would correspond to the effect of the breadth of the earth at the distance of the sun, and would determine that distance, provided the distance of Venus were known. Thus if E be the earth, V Venus, and S the sun, the line of



Venus's course seen from A will be lower than that seen from B, and the distance of the two courses will show the effect of the earth's breadth at the distance of the sun, and will, in fact, fix down this distance to a certain ascertainable quantity, if the distance of V from the earth were otherwise known. In short, after all the observations and calculations were made, it appeared that the distance of the sun is 23,984 times the earth's radius, or about 95,000,000 of miles. By railway travelling at the rate already supposed, this distance would occupy four centuries. The same operation gives the horizontal parallax of the sun 8″·6 (8·6 seconds); that is, to reduce the height of the sun when near the horizon to a measurement from the earth's centre, 8″·6 must be subtracted from the observed height. The horizontal parallax of the moon is about a degree.

110. The direct mode of proceeding for the planets Mercury, Venus, Mars, &c. is the same as that for the moon. But at an advanced stage of astronomical discovery, when the earth was proved to be in constant motion—in fact, to describe a circle round the sun at the distance above given—an entirely new base came to be furnished; namely, two different stations of the earth in this circle. After the exact determination of the sun's distance, we know how far the earth moves in a day, week, or month. If the earth goes in a circle round the sun at a distance of 95,000,000 of miles, the whole circumference or course gone over in the year will be about 600,000,000 of miles, and in a month 50,000,000; in a single day it will move over two hundred times its own diameter, so that a day's motion alone would be an immense enlargement of the base-line, or the displacement of the spectator.

111. Suppose, therefore, we wished to find the distance of the planet Jupiter. If it were perfectly at rest, or had no motion of its own, we should have to observe its place in the stars at two different times, say a month apart, and the angular difference of the two observations would correspond to the angle formed by a month's track of the earth at the distance of Jupiter—that is, at the first observation from E, Jupiter, G, would seem at A among the fixed stars; and when the earth had moved to E′, Jupiter would seem to lie at B, and the interval AB, or the angle at G, would be the angular displacement corresponding to the distance from E to E′; and if this distance were a month's motion of the earth, the angle would be so large in the case of any planet, that the errors of observation would be trifling, and the distance could be ascertained with great accuracy.



112. Of course, if Jupiter has a motion of its own, this

must be separately found out from its average course round the whole heavens, and allowed for in the above observation.

113. It is in this way that the distances of all the planets have been found, after a great deal of observation under many different circumstances. In such questions it is often necessary to find a quantity in a rough way first, and then use that to determine a second; which, being found, will assist in correcting the first in a new operation. For example, we have seen that, to find the sun's distance by the most perfect method, or the transit of Venus, the distance of Venus itself required to be known. But this distance cannot be accurately found without using the earth's motion to give a large base-line; and again, the length gone over by the earth in a day or a week is not known till its distance from the sun is known. Hence there must be a long series of trials, beginning at imperfect quantities, and comparing them with observations, till at last measurements are arrived at such as to agree with all the appearances.

114. After the great revolution in astronomy that we will have to explain presently, which proved that the sun is the centre of the motions of all the planets, it was found most natural to calculate their distances from him, after ascertaining the distances from the earth. The distances from the sun are nearly always the same, the distances from the earth are found very irregular; for example, the distance of Mars from the earth is at some periods four times as great as at others; but its distance from the sun is nearly the same always, and in so far as it changes, there is a regular uniform rate of change.

115. Hence it is, that after having performed the measurements of the distances of all the wandering bodies from the earth and from one another, the form of stating them is to say how far each body is from the sun, which appears to be the common centre of their movements through space. Thus Mercury, the nearest to the sun, is distant from him nearly *two-fifths* of the earth's distance; Venus, which comes next, nearly *three-fourths* of the earth's distance; the Earth itself is third in order from the sun; Mars succeeds, and is *one and a-half* times the earth's distance; after him come the small planets discovered within the last fifty years, and not seen by the naked eye, which go round nearly all at the same distance of about *two and a-half* times that of the earth. After them Jupiter succeeds at *five and a-fifth* times the earth's distance; Saturn *nine and a-half;* Uranus *nineteen;* and the new planet Neptune about *twenty-nine.* (See par. 147.)

116. We thus find that the different bodies are moving,

some comparatively near, and some very far away from us; and that besides passing over the face of the starry heavens, they have other motions that we cannot directly see; they may be at one time drawing nearer us, and at another retiring farther into the depths of space.

117. When the same methods of measurement were applied to the fixed stars, they seemed for a long time to fail. Two observations of any star made from different points of the earth's orbit, though at the enormous distance of 200,000,000 miles apart, gave no appreciable displacement or parallax. As a parallax of one second ($\frac{1}{3600}$) of a degree would imply a distance equal to 200,000 times that of the sun, and as it was certain that a parallax of that amount could be measured if it existed, it was inferred that no star was at least within that distance. More refined modes of observation have recently detected the parallax of several stars, and determined positively their distances. In stating these distances, it is convenient to take as a standard or unit the distance due to a parallax of one second—namely, 200,000 distances of the earth from the sun, or 20 millions of millions of miles. The nearest yet measured is a fine double star in the southern hemisphere (α Centauri), calculated to be a little greater than one such sidereal unit; Sirius, the brightest of the fixed stars, is at a distance of about four units, requiring upwards of twelve years for the transmission of its light.

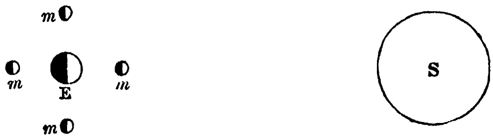
118. This creates a new distinction between the wandering and the fixed stars; the distances between the former, great when compared with distances on the earth, become as nothing when compared with the vast space that separates them from the nearest of the latter. We have thus an inner celestial system, containing the sun, planets, earth, and moon, at enormous distances when compared with our daily standards of measurement; but floating very closely together in a compact system, when we view them along with the celestial universe, whose nearest star is inconceivably remote from the most far-ranging member of the group. Of the inner world, called the *solar system*, we have obtained a very complete knowledge; of the outer universe, or the starry system, we know very little, and may never know much. What little insight careful observers have obtained into the starry system makes a branch by itself, distinct from the astronomy of the well-understood solar system, and is entitled Sidereal Astronomy.

FIGURES OF THE HEAVENLY BODIES.

119. Judging from the round appearance of most of the starry bodies, we are naturally led to conclude them to be

round balls. If they turn round about, so as to present sometimes one side, and sometimes another, and still have a round outline, they can be no other than round or spherical bodies; for a sphere is the only shape that has a round outline whichever way we turn it. Now, as we observe, by applying telescopes to the sun and planets, that they really do turn round and show different faces, and still appear roundish, we conclude with certainty that they have, on the whole, a round or spherical figure.

120. There are, however, two remarkable exceptions to the constant roundness of appearance that we have founded this inference upon. The *moon* is constantly changing her visible shape; and she has the full round face only at one part of her monthly course. More accurate observation, however, shows us that this arises from the moon being dependent for her light upon the sun, and upon our not being always in a position to see the whole of the lightened side. When the moon *m* is between the earth E and the sun S, her dark side is turned to the earth, and she is then invisible; when on the other side (and the earth not directly between her and the sun), her full lightened side is turned to the earth, and she appears a full round body. In other positions, only a part of the lightened half is seen from the earth, and she is then half light and half dark, or she appears as if she were only a section of a circle. The proof that she exists as a round solid body, even when not seen as such, may be obtained by watching her when she is new moon, or is merely a crooked streak of light. In this situation we may trace a fine ring of light round her whole body, showing her to be a circular mass.



121. The other exception to the usual roundness of appearance is the planet *Saturn*, which seems to change its shape very much. The irregularities were, however, explained by Hüygens, a Dutch astronomer, who showed that Saturn has a round mass like the other planets; but in addition to the central mass, there is a vast ring which whirls round at some distance from the body of the planet; the planet seeming, as it were, suspended in the centre of the ring.

122. Thus it appears that the heavenly bodies, so far as we can see, have the same round figure that we inferred our own

earth to have; but when we come to use instruments to measure their apparent breadths in different directions across their bodies, we find that there is in some of them a slight deviation from the perfect circular form. In Jupiter the deviation is very remarkable; his greatest breadth exceeds his least by about $\frac{1}{11}$th of the whole (or as 107 to 100). In Saturn, too, a considerable flattening is observed; in the other planets it also exists, but much less than in these two; in the moon it is exceedingly small. But this peculiarity of not being perfect spheres, or of being more or less flattened, we found to hold in the earth, whose polar diameter is 26½ miles shorter than the equatorial, or about $\frac{1}{300}$th of the whole. The difference of the greatest and least diameters of Venus is almost the very same; so that, in strict language, the *figure* of the bodies composing the solar system is what is called a *spheroid* or flattened sphere; the degree of flattening being greater in some than in others. No figure is discernible in the remote stars; they are simply luminous points, which no telescope is able to magnify into a distinct surface, or into what is called a *disk*—that is, a face of some breadth with an outline of an assignable figure.

MAGNITUDES OF THE HEAVENLY BODIES.

123. Knowing the distances, we can find the real sizes of bodies from their apparent size, or from their dimensions taken by an angular instrument. If an object be a mile off, and if its breadth make an angle of a degree at that distance, its real size is determined by these two quantities. Thus the *moon* being about 237,000 miles from the earth, and having an angular breadth in the sky of somewhat more than half a degree, its actual breadth must be about two thousand miles. The accurate estimate is 2160 miles, rather more than a fourth of the diameter of the earth.

124. The *sun* has almost the same apparent size in the sky as the moon; but being at about 400 times the distance of the moon, he must have 400 times the breadth of the moon to appear equally large. In fact the sun's diameter is 110 times that of the earth.

125. On comparing the apparent breadth of the planet *Mercury* with its distance, we find that it must have a real breadth of two-fifths of the diameter of the earth. *Venus* is almost equal to the earth. *Mars* is only one-half of the breadth of the earth. The planets between Mars and Jupiter are very small masses. *Jupiter* is the largest of all the planets; his diameter is 11¼ times that of the earth; *Saturn*,

the second in size, 9½ times the earth; *Uranus* 4¼ times; and Neptune 6½ times.*

126. The solid contents of the various bodies can easily be found from their diameters. The cubes of the above numbers will give the proportions of the solid contents to the earth. Thus the sun, whose diameter is 110 times the earth's, will have a bulk more than 1,000,000 of times the bulk of the earth; so that not only is the sun vastly greater than the earth, but all the planets put together would be a mere fragment compared with him. The magnitudes of the remote fixed stars must be a still greater mystery than their distances; we can only imagine that they need to be very large, and intensely lighted up, to appear at all through such enormous intervals of space: they must be at least equal to the sun, and many of them may be much greater.

127. In making minute observations upon the bodies of the solar system to find their magnitude, other irregularities of figure are observed besides the flattening above-mentioned. Some of them have evidently a mountainous surface like the earth. Thus the surface of the moon is seen to be made up of mountains and valleys. (See fig.) The heights of some of the mountains have been measured from the shadows that they cast when near the edge of the illuminated portion of the moon. If the body were a smooth sphere, this inner edge would be of a perfect circular outline; its jaggedness shows the irregularity of the ground, and enables us to appreciate the elevation of the mountains: the highest of these have been calculated at 1¾ English miles. Mercury and Venus also exhibit traces of a mountainous surface.

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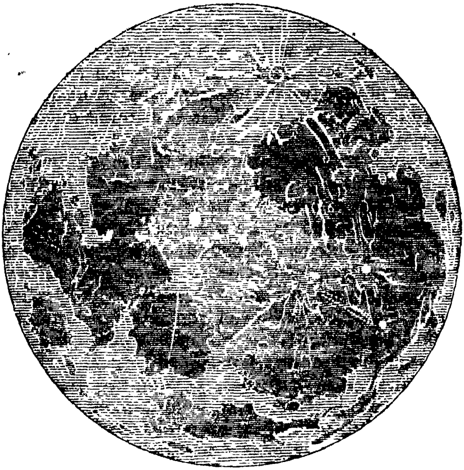
* The following are the diameters of the planets in English miles:—

The Sun,	882,000	The Earth,	7,912	Saturn,	79,042
Mercury,	3,140	Mars,	4,189	Uranus,	35,112
Venus,	7,800	Jupiter,	89,170	Neptune,	50,000

Some idea may be obtained of the comparative size of the principal objects of the solar system, by supposing a globe of two feet diameter, placed in the centre of a level plain, to represent the sun; a grain of mustard-seed, placed on the circumference of a circle 164 feet in diameter, for Mercury; a pea, on a circle of 284 feet, for Venus; another pea, on a circle of 430 feet, for the Earth; a large pin's head, on a circle of 654 feet, for Mars; forty minute grains of sand, in circles of from 1000 to 1200 feet, for the asteroids, now (1856) ascertained to be of at least that number; a moderate-sized orange, on a circle of nearly half a mile in diameter, for Jupiter; a small orange, on a circle of four-fifths of a mile in diameter, for Saturn; a small plum, on a circle of a mile and a half in diameter, for Uranus; and an ordinary plum, on a circle of two miles and a half, for Neptune. It is calculated that the united mass of the whole of the ascertained planets is not above a 600th part of the mass of the sun.

128. Another peculiarity connected with the measurement of size, is the existence of atmospheres. These cannot be seen directly, except they be so dense as to give a strong hazy outline; but when one body passes over another, as sometimes happens, the contact of the edges shows if there be any substance around the planet to bend the rays of light, in the manner already described in reference to the refraction of the earth's atmosphere. When the moon passes over a star, the disappearance of the star would be delayed, and its reappearance hastened, by a lunar atmosphere; and the whole period of the *occultation*, as it is called, would be shortened. But as this effect does not happen, it is concluded that the moon has no atmosphere; and the inference is confirmed by all other observations. There is, in fine, no symptom either of air or water on her surface. The case is, however, different with the planets. Venus has an atmosphere about as dense as the earth, and the planets generally appear to have atmospheres; so that there is a possibility, as far as we can see, of the planets being inhabited like the earth.



Telescopic appearance of the Moon.

ROTATIONS OF THE HEAVENLY BODIES.

129. The close observation by instruments, which reveals such points as we have just mentioned, shows also that the

bodies of our solar system have generally a whirling motion besides their forward courses through the stars. When we observe a planet's surface minutely, we can see that it has well-marked features, which we can recognise when we see them again. Now, on watching the surface of any of these bodies for a length of time, we find it gradually changing; one face disappears, and another comes on; but in the course of time the old face returns again, and is succeeded by the same series of different faces. It becomes evident that the body is constantly rotating, and that the changes that we see arise from this motion. By watching the time between two appearances of some one notable mark on the surface, we can know the time of a complete rotation; and by observing many of these, we can see if the whirl is kept up at one steady and uniform speed.

130. Shortly after the invention of the telescope, Galileo applied it to examine the surface of the sun. He found that there were scattered over the lighted disk large dark spots, which sometimes remained for weeks, although none of them were entirely permanent. From the motion of these spots, he discovered the rotation of the entire body of the sun, as if on an axis; and this rotation has been confirmed by all succeeding observations, and has been found to occupy 25½ days. Considering the bulk of the sun, this would give an extraordinary speed to the motion of the equatorial surface. Mercury and Venus are so brilliantly lighted up, from their being near the sun, that it is not easy to find fixed marks on their surfaces; but from what has been observed, it is concluded that they have both a whirling motion, and that a complete rotation of each takes about a day. The rotation of Mars is very conspicuous; each turn is made out to occupy 24 hours 39 minutes 21 seconds. Moreover, in a clear case of rotation, the *direction* of the whirl can be discovered; it can be seen which way the noted points are moving, whether up, down, or across; and this will inform us of the direction of the axis. If the spots move directly across our view, the planet spins upright; if they move parallel to the equator of the heavens, the axis will point to the celestial poles. In the case of Mars, it is seen that the axis is inclined to the ecliptic at an angle of 30° 18′. The direction of his motion, as judged from the course of the superficial marks, is the great forward direction of west to east. Jupiter has a very rapid whirl: he accomplishes an entire rotation in 10 hours; the more remarkable, considering his enormous size. Saturn takes 10¼ hours. All the rotations are, as in the case of the daily revolution of our own planet, from west to east.

131. There is a striking coincidence between the rates of whirling as here given, and the flattenings previously noticed. The bodies that whirl fastest are most flattened; Jupiter has the quickest rotation, and the greatest deviation from the circular shape. The moon, on the other hand, whose flattening is very small, has a slow rotation, occupying 27¼ days in each turn. Moreover, the shortest diameter in all cases corresponds to the axis of the motion. The distance from pole to pole of each body is smaller than the diameter across the axis, as we found to be the case in the earth. This coincidence of flattening with whirling is something more than a mere accident; the one is proved to be the effect of the other. A body whirled round, if soft in the texture, always becomes bulged out in the middle, and shortened between the two ends. We are thus taught that the actions that occur in the things that we handle on the earth, take place also in the great scale of the heavens. A revolving planet loses its round shape in the same way as a ball of clay whirled on a potter's wheel.

132. The next subject of consideration should be the *courses* of the wandering bodies, or the exact paths that they describe in their motions round the starry sphere. After knowing their distances, and being able to say when they go farther off or come nearer us, we are prepared to inquire into the actual figure that they trace in their career through space, and to see whether they adhere to circles, or to any other regular figures. Before measuring their distances, it was quite impossible to lay down their accurate course; we could not well know when they retired deeper into space, or emerged into closer neighbourhood. We may observe here that, having measured one distance of a planet, or of the sun or moon, and observed its *apparent breadth* at that distance, we can discern changes of distance from changes of breadth. Thus the moon's breadth is sometimes more and sometimes less than half a degree, proving that it is one time nearer us than at another time. The breadth of Mars varies from 4 to 18 seconds of a degree, showing enormous variations in his distance. When he is 4 seconds broad, he must be 4½ times farther off than when he is 18 seconds broad. Jupiter also varies from 30 seconds to 46 seconds. In short, by accurately measuring the breadth by fine angular instruments, we can discern at once whether the body is farther or nearer than ordinary. We ought, therefore, now to describe what is the actual figures of the tracks gone over by these wandering bodies; but it is convenient, in the first place, to discuss the great question already started, of the Movement of the Earth. Does the earth stand still, a

rigid motionless mass, in one fixed spot of universal space, as we are apt to imagine it, and as the human race devoutly believed for many ages; or can it be proved that it has motions in space like the motions that we plainly observe in some of the heavenly bodies?

MOVEMENTS OF THE EARTH.

133. It has been maintained by all astronomers for nearly three centuries that the daily revolution of the starry sphere, and the annual motion of the sun round the heavens, are not *real* motions, but merely apparent or supposed motions, arising from two distinct movements of the earth; and that the great firmament of stars, and the sun, the centre of the planetary movements, are actually at rest. This view is called the Copernican theory of the world, from Copernicus, a Pole, who published it in the year 1543.

134. The movements of the earth are—1*st*, *Rotation*, that is, the body of the earth revolves or whirls round the axis that passes between pole and pole in the direction from west to east, completing a revolution in 23 hours 56 minutes. 2*d*, *Translation*, which means that the earth, instead of being fixed in one spot, moves through space in a wide circle surrounding the sun, at a distance from him of about 95,000,000 of miles. Let us consider first the movement of *rotation*.

135. It is not easy at first sight to believe that the earth is in a constant whirl, carrying us all round and round at a velocity of upwards of 1000 miles an hour at the equator, and about 600 miles an hour in Great Britain. We have no consciousness of being borne round at such a rate. We seem rather to stand on a foundation fixed and immovable. But this argument from our feelings is insufficient; for we are always apt to suppose the place we stand on to be at rest, unless we ourselves are making some exertions to move or to resist motion. Standing on the deck of a ship at full sail, and looking down at the water, we suppose it to be rushing past the ship, and the ship itself to be at rest. So when riding smoothly in a carriage, and seeing from the window everything passing by, our natural disposition is to believe that we ourselves are sitting still unmoved, and all outward things rushing past us in a constant current. If we are shut up in a vehicle whose motion is perfectly smooth, we cannot tell, from our feelings, whether it moves or not; if we see things moving outside, we cannot know directly whether they are moving past us, or we are moving past them. Such is our case with the motion of the earth. It goes on in a steady whirl, without stoppages,

or shocks, or any of those joltings that give us the feeling of motion; it carries us quietly round to face every side of the heavens, and when we find ourselves looking now upon one set of stars, and shortly afterwards on another, we suppose them to be moving round us, and not we round them. But our own motion would have the very same effect as the actual rotation of the starry firmament, and it is only by indirect inquiries that we can be sure which is the actual motion—whether the rotation of the stars from east to west, or the rotation of the earth from west to east; whether the rising of a star in the east is a real motion of the star, or an opposite motion on the earth which brings us round to face the star. The proofs that this great appearance arises from the rotation of the earth, and the repose of the stars, are these:—

136. 1*st*, Although it was natural to the ancients, who thought the earth of immense extent, and the heavenly bodies small in comparison, to believe that the heavens should sweep round the earth, the case is now completely altered, when we know that the earth is only equal to a fourth or fifth-rate planet; that it is a mere handful compared with the sun; and in regard to the vast universe, like a single leaf in a forest, or a grain of sand on the sea-shore. It is not credible that so insignificant a body should have such influence over the starry vault as to compel it to perform this daily circle, which, considering the distances of the stars, would involve a rapidity of motion infinitely beyond any motion that we know of, or can imagine. If the turning of the earth would cause the same succession of appearances, it is at least more likely than the other.

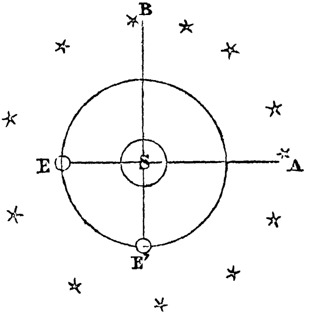
137. 2*d*, The irregular wandering of the near bodies in the starry sphere, shows that the influence of the earth is not so perfect over the objects in her neighbourhood, as we must suppose it to be over the immeasurably remote luminaries of the sky.

138. 3*d*, The earth being proved to be exactly like the other planets in most respects—to be a round ball of a size greater than some of them, and less than others; and it being seen that the planets all rotate—there is a strong probability that the earth also rotates. Venus, who is nearly of the same size as the earth, revolves in about a day; and it is therefore not unnatural to suppose that the earth may do the same.

139. 4*th*, It is proved that a whirling motion in a body that may have once been soft, is sure to make it bulge in the middle, and flatten at the ends where the poles lie. This is seen in all the planets, and is greatest in those that revolve most quickly. Such a flattening exists in the earth; the earth is thicker at the equator than between the poles, as it ought to

be if it were a whirling mass. Moreover, the amount of the flattening is just about equal to the flattening of Venus, whose size and time of revolution nearly agree with the earth.

140. Let us inquire next into the proofs of the *translation*:—Instead of the great sun actually moving round the heavens once a-year, at a distance of 95,000,000 of miles from the earth—in other words, describing a circle round the earth at that distance—it may be shown that the sun is the fixed centre, and that the earth describes the circle round him. The celestial appearances would be the same in both cases. If the earth shifted from place to place, and moved round the sun, we should see the sun appearing to shift his place among the stars. Thus if S be the sun, and E the earth, a spectator on the earth looking at the sun would find him lying at A among the stars; if the earth moved round to E′, the sun would then be seen as lying at B, just as far round among the stars in the direction AB, as the earth itself is round in its course in the opposite direction EE′. So that every day's movement of the earth would shift the place of the sun among the stars; and the effect of a complete circle of the earth round the sun would be to produce a complete circle of apparent motion of the sun round among the stars. So that the sun's *appearing* to move proves nothing: he must appear to move exactly as he does, if the earth were in motion and he at rest. The proofs that decide which is the moving body are these:—



141. 1*st*, The sun is so much a larger body than the earth, that it is more natural to conceive him compelling the earth to move round him, than himself to be moving round the earth.

142. 2*d*, All the other planets are seen to move in circles round the sun, and there is nothing about the earth to make us suppose that it should differ from the rest. It can be proved by measuring and calculating distances, that the courses of all the planets are very nearly circles round the sun, some farther off than the earth, others nearer.

143. 3*d*, The next proof arises from the retrograde motion of the planets, which precisely agrees with the supposition of a motion on the part of the earth. A person standing on the

sun, and looking abroad among the planets, would find that they all move steadily onwards in one constant direction from west to east, never halting or turning backwards, and scarcely ever slackening their speed. But if, instead of looking out from the sun, we were to look out from a body itself shifting, the real motions of the planets would be confused with the motions of the observer, and might even sometimes seem opposite to what they really are. If, for example, we on our planet were moving onward much faster than another planet near us, we would necessarily suppose it going backwards; its place among the stars would seem to be retreating; that is, there would be an apparent retrograde motion, while, in reality, the planet is moving steadily forward. When the earth, in its circular course, comes to turn inwards, instead of running parallel to the other, the retrogradation ceases, and the planet appears really to be going forwards. But there will always be a certain place where the swift motion is so far inclined to the direction of the slow, that they seem to be going forward at an equal pace; in this case the other planet will seem to stand still. Again, when our swift planet is on the other side of its circle, going contrary to the slow planet, the latter will seem to advance with great rapidity through the heavens.

144. Such irregularities in the appearances of movements that are in themselves regular, must arise if the earth be in motion. And when the irregularities that we actually observe in the planets are compared with the place and motion of the earth at the time, we find that they exactly agree. Mercury and Venus, which are nearer the sun than the earth, and describe their circles more rapidly, are found to have the precise retrogradations, stationary periods, and accelerations that would arise from the movement of the earth round the sun in a circle more distant than theirs. And Mars, Jupiter, Saturn, and the other planets whose circles are outside the earth's circle, and which are much slower in their movements, are actually made to retrograde at those very times when, from the swifter motion of the earth, they would necessarily do so. And it is very unlikely that the sun would be the centre of all the other planetary courses, and be itself moving, planets and all, round the earth; although this supposition was actually maintained by some astronomers before the final acceptance of the doctrines of Copernicus.

145. This displacement of the heavenly bodies by the motion of the earth round the sun is called the *annual parallax*, which we already alluded to in explaining the method of measuring the larger celestial distances. And as observations made on the surface of the earth have to be converted into

observations from the centre, by correcting for the parallax arising from the earth's magnitude, so, after proving the movement of the earth, we must reduce observations made upon it to observations made from the sun—the only fixed point in the system, and the only point that can yield observations that may be properly compared with one another. The reduction to the centre of the *earth* being called *diurnal parallax*, the reduction to the centre of the earth's annual movement, or the centre of the *sun*, is called *annual parallax*. Both quantities can be easily determined for all bodies if the distances be known; and if either can be found by observation for any one body, the distance of that body can be deduced from it.

146. *4th*, The most decisive proof that the earth is in motion round the fixed sun, arises from what is called the *aberration of light*, or a peculiar displacement of the heavenly bodies, owing to the time spent in the passage of light. It was found out nearly two centuries ago, that the light of the sun, or of the planets, occupies time in passing to the earth. The sun's light requires 8 minutes to reach the earth, which shows it to travel at the rate of 192,000 miles a second. Now if the earth were perfectly at rest, no particular consequences would happen from this; except that, if a planet were farther off at one time than at another, its appearances would be later in reaching the earth. But if the earth be in motion through the showers of rays, the direction of their stroke will be changed, and the supposed places of the bodies they come from will be changed also. If a shower of rain fall upon a person standing still, he will feel exactly the direction that it comes from; but if he is rushing forward, it will strike him in a more slanting direction. If formerly it fell downright, it will now seem to have a motion slanted towards his breast, and he will imagine it to be moving partly downward, and partly from before him in a level direction. If the rain were shot out from any particular machine, the machine would seem to the person at rest to be overhead; but to the person in motion it would seem to be inclined, so as to strike his face, as well as the crown of his head. Now as the earth moves through the showers of light, and receives them in this moving state, their stroke is not direct according to their own motion, but mixed up with the earth's motion; and the supposed direction of the bodies is ahead of the real one. The stars are thus put out of their true places into apparent places; and the amount of displacement will depend on the velocity of the earth. If the earth moved as fast as light, the displacement from an oblique stroke would be half a quadrant. But as the motion of the earth is only about the ten thousandth part of that of light, the dis-

placement becomes very small; but it is still a measurable quantity, being about 20 seconds, or $\frac{1}{180}$th of a degree. The manner of determining whether such an effect really happens, is to compare the places of the same stars, when the earth is at opposite sides of its circle. On one side of the circle it moves one way in the light-showers, and throws the stars forward according to its own motion; on the other side it has an opposite course, and throws the same stars before it as it now moves—that is, contrary to their former displacement. We may therefore see by observation whether the apparent places of the stars are really different at an interval of six months, by the exact amount due to this effect. Now it was discovered last century by Bradley that this displacement actually takes place over the starry heavens; and the amount of it in each case corresponded with the calculation from the two motions of light and of the earth. The displacement is greatest in stars near the ecliptic (where the earth *actually* moves, as the sun appears to move), and decreases according to the distance of the bodies from the ecliptic.

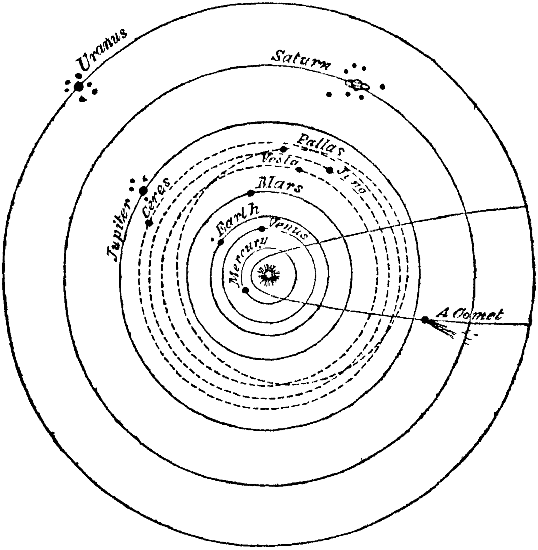
147. This great discovery is the crowning proof of the motion of the earth; for the appearances could not be produced in any other way than by the earth describing a vast circle round the sun at the distance of 95,000,000 of miles. This is also one of the *corrections* (in addition to refraction and the two kinds of parallax) which has to be applied to observations in order to obtain the true place of a celestial object.

THE SOLAR SYSTEM AS A WHOLE—LAWS OF KEPLER.

148. The establishment of the double motion of the earth—the daily whirl and the annual circle—leads us to look upon the sun as the true centre of the solar system, and to distinguish the solar system from the sidereal system, or the wide universe of stars. We must now regard the earth as one of the wandering bodies, similar to Venus, Mars, and Jupiter, and, like them, circling round the great fixed luminary; and when we wish to find out the real tracks gone over by the different bodies, we must view them, not as they appear from the earth, but as they would appear from the sun. We must perform a series of calculations, which will determine whereabout among the stars each planet is at any time as seen from the sun. This is called finding the *heliocentric* (or sun centre) place of a body; the place from the earth being the geocentric (earth centre) place; that is to say, if we find the right ascension and declination (or latitude and longitude) of Jupiter as seen from the earth, we must calculate by trigonometry what

are the right ascension and declination of Jupiter as seen from the sun. So with actual distances. It is necessary to find for every day or hour the distance of every one of the planetary bodies from the sun, which may be calculated when we find the distance from the earth; also, in regard to the velocity of their movements, we must find what it would be if noticed from the fixed centre of the whole system. It would be unreasonable to expect anything like regular rates of movement which we might count upon and predict from, except by supposing ourselves to look out from the natural centre.

149. The solar system, according to the modern view, would be represented in a figure thus:—In the centre of the whole is the sun, the largest body, and the source of light to all the others. In a circle round it, at an average distance of 87,000,000 of miles, and completing the course in about 88 days, is the planet Mercury. In a second circle beyond Mercury, Venus moves; its distance 68,000,000 miles, its time of revolution about 225 days. Next beyond Venus is the circle of the Earth, at a distance of 95,000,000 miles, and requiring



Solar System to the Orbit of Uranus.

a period of revolution equal to 365¼ days. Still larger is the orbit of Mars; its distance 144,000,000 miles, and period of revolution 687 days. Enclosing it are the circles of the small planets, or *Asteroids*, as they are frequently termed—Vesta, Juno, Pallas, Ceres, and thirty-six more, recently discovered—all at nearly the same distance from the sun. Beyond these is the wide circle of Jupiter; its distance about 490,000,000 miles, its period, 4330 days—nearly 12 years. Still more remote is the circle of Saturn, the distance being 906,000,000 miles, the period round the sun, 10,747 days—about 30 years. Next is the circle of Uranus, distant 1,800,000,000 miles, traversed in 84 years. Lastly, we have the lately-discovered planet Neptune, whose distance is nearly 2,900,000,000 miles, and period, 164½ years.*

150. Such is the system of sun and planets; but several of the planets are themselves centres for other bodies, called moons or satellites (Lat. *satelles*, an attendant), which move round them, as they themselves move round the sun. (See diagram.) Our moon acts this part to the earth. Jupiter has four such; Saturn, eight; Uranus, six; Neptune has one for certain, the suspicions of a second have not been confirmed. These are called the *secondary* systems.

151. Having thus attained a view of the true nature of the solar system, it is necessary to inquire more particularly into the paths and rates of movement of the different bodies, to see if any fixed laws prevail, or any regularities that may enable us to predict the future from the present. The first discoverer of uniform laws among these movements was the celebrated Kepler; and the three great doctrines of planetary movement found out by him are called the "laws of Kepler."

152. A law means a fixed relation between *two* things, such that knowing one is to know the other also. Thus it is a law that running water polishes rocks—that is, if we see a mountain-current, we may know, without looking, that the bed is water-worn; or if we see a track of rounded stones, we know that water has been running over them, although we may never have seen the water itself. By means of a law, one observation always discloses at least two facts. When we

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* The following are the *signs* generally adopted by astronomers to indicate the sun, moon, and major planets:—

🌞 ⊙ Sun,
☿ Mercury,
♀ Venus,
⊕ Earth,
● ☽ ○ ☾ Moon,
♂ Mars,
♃ Jupiter,
♄ Saturn,
♅ Herschel or Uranus,
♆ Neptune.

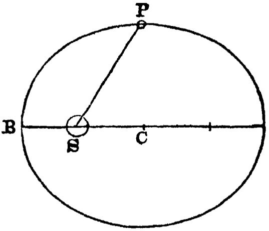
find that the planets are all flattened, according to the rate of their whirl, we lay it down as a law that the whirling is accompanied by the flattening; so that if we discovered a new planet, and saw it to be flattened, we should say at once that it revolved on its axis.

153. Now the laws of Kepler show fixed connections of this kind among the quantities connected with the planetary movements, and thus increase the knowledge that we derive from our actual observations.

154. The *first* law is as follows:—*The angular velocity of a planet's movement in its circuit is inversely as the square of its distance from the sun.*

We have hitherto spoken of the courses of the planets as circles, which they are very nearly, but not exactly. When their distances from the sun are calculated for different parts of their course, these are found to vary; and Kepler has stated a law which connects the change of distance with the speed of the motion: when the distance *increases*, the speed *diminishes;* and at the least distance we find the greatest speed. The calculation, however, must be made by squaring the distance. Thus if the distance increased from 9 to 10, the velocity would diminish at the rate of 100 to 81. If, therefore, we know the change of velocity, we will be saved from *observing*—for we can *calculate*—the change of distance. This law is called the law of *equal areas*, because the areas swept over by the line joining the sun and planet are equal in equal times. This line is termed the *Radius Vector.*

155. 2*d*, *The path of the planets round the sun is an ellipse, the sun being in one focus.*



The ellipse, or oval, may be compared to a circle, if we suppose it described round *two* central points. It is a regular or symmetrical figure, and its properties and peculiarities were well known to the ancient Greek geometers. Kepler made a very great discovery in finding that the track of the planets, although not a circle, is yet a simple and well-known figure. It is possible from this law, combined with the first, to predict the place of any planet at any given time. Thus let BPA be the oval track of the planet, S the sun in one of the foci or centres; then if the whole time of revolution be known, and also the shape or proportions of the ellipse (which are determined if we know the length BA, and the distance between the focus and the middle point C, called the *eccentricity*); and supposing the planet to start from some known place, such as B, it can be calculated exactly where it will be in any given number of hours, days, or years; or, on the other hand, if the place arrived at be given, the time of coming there may be calculated. But without identifying the figure of the orbit with some known and familiar figure, these calculations and predictions would have been impossible.

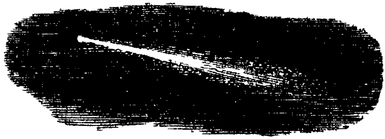
156. *3d*, The two first laws refer to the motions of a single planet; the third law shows a relation between the motions of all the planets, or all the bodies that revolve round the same centre. It is, that *the squares of the periodic times of any two planets are to each other as the cubes of their mean distances from the sun;* that is, if there be two planets, and one farther off than the other, the near planet will perform its revolution quicker than the other, and according to a fixed proportion. Thus the periodic times of the earth and Mars are 365¼ and 687 days, and their distances as 100 to 152⅓; and by Kepler's law the square of 365¼ is to the square of 687 as the cube of 100 to the cube of 152⅓; which, on making the calculation, will be found to be the case. This law goes still farther to shorten the labour of observation, and increase the knowledge derivable from what is observed. Thus suppose a new planet is discovered, as Uranus by Herschel: by the method of annual parallax, or of observed displacement by the earth's motion, its distance can be found; and by knowing the distance, the time of revolution can be determined, without waiting till we see it go actually round the heavens. Uranus has not been once round the heavens since its discovery in 1781; but the time that it will occupy in its revolution was found out long ago, and could have been determined independently of its observed rate of motion. If we know well the periodic time and the distance for one planet, and if we know one of these quantities for any other, the second quantity is supplied by the above proportion; and there is no need of actual observation to find it.

157. This third law gives a sort of family relationship to all the bodies of the solar system, and shows that though they move widely apart from each other, yet their connection with a common centre maintains harmonious relations throughout the whole.

158. These three laws, then, are a basis for predicting the future courses of the planets, when once certain quantities are known respecting them.

159. But the same laws apply to the secondary systems, or the revolutions of satellites about planets. The moon, if undisturbed by distant influences, would obey the first two laws in its motion round the earth; its velocity would quicken as the square of its distance lessened, and its figure would be an ellipse, the earth being in a focus. So the satellites of Jupiter follow the same rules; and, moreover, they exemplify the third law—for if the distances of two of them are compared with their times of revolution about Jupiter, they show the very proportion laid down by Kepler. The same holds of the seven satellites of Saturn.

160. There is a class of bodies attached to the solar system, and revolving round the sun as their centre, but differing very much from the planets. These are the *comets* (Latin, *coma*, a lock or brush of hair). They have in general the appearance of an irregular cloudy patch of light, which grows stronger towards their centre; and they often send out long streaks of haze, which are called *tails*. They are evidently of very thin material; they seem to shine by their own light, as if they were fragments of the solar atmosphere; but in their nearest approach to the sun, they get very much expanded, and more intensely lighted up. Now these bodies are found to obey the same laws as the planets; they revolve in ellipses: but whereas the ellipses of the planets are very nearly circles, those of comets are often long and narrow, or very eccentric. (See diagram, p. 72). The planets are mostly confined within the zodiac, or the neighbourhood of the ecliptic; the comets may be found in all parts of the heavens: but still if we fix on any one of them, we find that, except for certain disturbances, it is bound by the same laws of distance, velocity, and figure of orbit as the planets. These comets abound in great numbers, probably to the extent of thousands. Several hundreds have been recorded, and some of these of enormous size and striking appearance. In the days, not long gone by, when celestial appearances were supposed to indicate the fate and fortunes of the inhabitants of the earth, comets were looked upon with terror and alarm.



161. The solar system, then, consists of the central sun, a huge mass with a burning fiery surface, which yields heat and light without seeming to decay; a series of *primary* planets, now seventeen in number—the earth being one, and five of

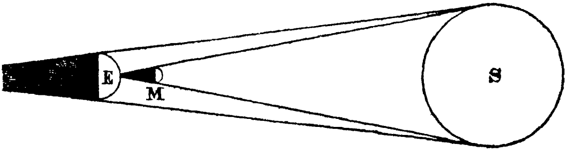
them being centres of attendant moons; and lastly, an innumerable host of comets, having long eccentric paths, such that at one end they go very near the sun, and at the other far away out of sight. Besides these, there seems to be a number of small fragments floating in the solar system, which occasionally descend upon the earth as *meteoric stones*.

CONFIGURATIONS OF THE HEAVENLY BODIES.

162. The various bodies of the solar system, in their apparent motions through the stars, give rise to peculiar aspects and conjunctions, some of which have very great interest.

163. The most remarkable of these are *eclipses*, or the apparent extinction of a body by some other one passing between it and the sun. Thus when the moon is on the opposite side of the earth from the sun, it sometimes happens that the earth is exactly in the way between the sun and the moon; so that the moon is deprived of light, or thrown, as it were, into the earth's shadow—in other words, eclipsed, and nearly blotted out of the heavens at the very moment of her greatest fulness and splendour. These eclipses happen once or twice every year.

164. When the moon is on the same side of the earth as the sun (see fig.), she may happen to come straight between the sun and the earth, and interrupt the passage of the light to some portion of the earth. The earth is then in the moon's shadow, and we experience the still more grand event of an eclipse of the sun; which, however, is rarely so entire as eclipses of the moon. The earth being about four times as broad as the moon, its shadow is vastly larger in proportion to the moon, than the moon's shadow in respect of the earth; hence the moon suffers the largest and most frequent eclipses.



165. These eclipses, like all other things about the heavens, can be predicted with almost perfect accuracy. It is also possible to calculate backwards, so as to find the probable date of remarkable eclipses recorded to have happened in antiquity. Thus a great solar eclipse is said to have prevented a battle between the Lydians and Medes somewhere about

six centuries before Christ; and by calculation it is found that an almost total eclipse of the sun (a very rare occurrence) happened on the 30th of September, 610 B.C.; which thus settles a great dispute in the dates of ancient history.

166. The satellites of Jupiter suffer frequent eclipses, from the immense body of Jupiter coming between them and the sun, or their passing into Jupiter's shadow. They thus show the very curious appearance of being suddenly extinguished from the sky, and then in a little coming into view again. Some one or other of Jupiter's satellites are eclipsed almost every night, and the times of each can be predicted.

167. Another effect that sometimes happens is the *occultation* of one body by another; as when the moon passes over a star or planet, and hides it from our view. This is quite different from an eclipse, which requires something to lie between a planet or satellite and the *sun*. The great breadth of the moon enables it to pass over a considerable number of stars every month.

168. The *inferior planets*, as Mercury and Venus are called, sometimes cross the sun's face, on which occasion they may be traced by a telescope as a dark speck moving from one edge over to another, and then disappearing. These are the *transits*, already alluded to as of importance in ascertaining the sun's parallax and distance.

169. In the times when people's fates and fortunes were predicted from the positions of the planets at the hour of their birth, much stress was put upon *conjunctions* and *oppositions*. When two bodies are in the same quarter of the heavens, so as to be near one another, or have the same *longitude*, they are said to be in *conjunction;* when they are half a circle apart in longitude, they are in *opposition*. Astronomers use the sign ☌ to indicate conjunction; and ☍ to indicate opposition.

THE CALENDAR.

170. The celestial motions have in all ages furnished the standards of time. The daily course of the sun makes our *day*, the revolution of the moon about the earth gives the *month*, and the return of the sun to the equinox determines the *year*.

171. The sidereal day is the only invariable standard of time. It is the same in all seasons and in all years. It depends on the apparent rotation of the starry sphere, which arises from the actual rotation of the earth—a perfectly uniform movement. The solar day is not only longer than the sidereal day, it is also of unequal length at different times of

the year. When the earth is in that portion of its elliptic orbit nearest the sun, the sun's apparent movement, by the first law of Kepler, is quicker than the average, and its retreat among the stars being thus greater, the difference between its day and a day of the stars is more than four minutes; in the contrary situation the difference is less, or a solar day is under twenty-four hours. Hence a day of our clocks is not the actual solar day, but the *mean* or average solar day.

172. A year, for the purposes of life, must be a complete circle of the seasons, called the *tropical* year; or it must be calculated from equinox to equinox. But owing to the retreat of the equinoctial points, this is less than a sidereal year (the time of a complete circuit of the sun among the stars) by about twenty minutes. Moreover, the tropical year is not perfectly constant; it is now about 4 seconds shorter than it was two thousand years ago. Its accurate length is 365 days 5 hours 48 minutes 49·7 seconds.

173. It is desirable to commence the year at the beginning of a day, or at midnight; which, however, cannot be done without going wrong a few hours every year. To correct this error is the purpose of the *calendar*. The first correction that was made was introduced by Julius Cæsar, and called the "Julian Calendar;" namely, to add a day to every fourth year (leap year), so as to make up for the surplus fraction above 365 days. If this surplus were exactly 6 hours, no more would be needed; but being less than 6 hours, the addition of a day to leap year is too much; and the consequence, in the course of 1600 years, was an error of 10 days. This was remedied under Pope Gregory XIII., who introduced the new correction of omitting to add the 366th day on the leap year that begins a century; that is, every twenty-fifth leap year is to be a common year of 365 days. The error that had accumulated since Julius Cæsar was corrected by striking out 10 days out of the month of October 1582 (passing from the 4th to the 15th in one day). This made what is called "new style;" and the reckoning, with the above additional correction, is called the "Gregorian Calendar." New style was introduced into England in 1752. Before that date the year commenced on the 25th of March; but instead of suffering the year 1751 to run on till March, it was cut off before the end of December (to omit the accumulated error), and 1752 was commenced, the first day being called the 1st of January.

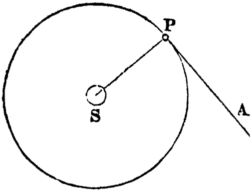
MECHANICAL OR PHYSICAL ASTRONOMY.

174. Not long after Kepler had made those remarkable discoveries, which completed the view of the regular courses and periods of the celestial motions; the *causes* of the motions, or the powers and forces whereby they are sustained, were also discovered by Sir Isaac Newton. He was the first to show that the vast planetary balls whirl about their own centres, and fly through the celestial spaces, on exactly the same principles as a cannon ball or a stone thrown into the air. The mechanical forces that we are familiar with on the earth, are the forces that carry on all the movements of the solar system. But it is possible to calculate by mechanical principles how far a cannon ball will fly under a certain stroke—what figure it will describe—what will be its rate of movement—and in what place it will be at any given instant. And Newton found that the very same calculations could be applied to a celestial ball. If we knew its speed at any one moment, the direction of its course, and its distance from the central body, we might find, according to the regular rates of moving bodies, where it would be at any future moment. This is to make the predictions of the heavenly bodies a *mechanical* question. A planet circling round the sun is considered as similar to a stone at the end of a sling, or a mass of matter on the rim of a wheel; that is, it is supposed to be sustained between two forces—one holding it in towards a centre (*centripetal* force), the other urging it to fly off at a tangent (*centrifugal* force).

175. The principles of celestial mechanics, therefore, are the principles of motion discovered from the observation of bodies on the earth; they are the three Laws of Motion and the doctrines of the Composition of Forces, as illustrated under MATTER AND MOTION (vol. i.), and the doctrine of Universal Gravitation.

176. The fall of unsupported bodies to the earth is the most familiar action in nature. But it is not two centuries since Newton discovered that this action extends to the moon, the sun, and the planets. He proved that the moon is constantly falling towards the earth, and would fall in to it, but for another motion she has, which is always carrying her off, and would of itself shoot her far away into space in a straight course; so that her actual circuit is the balance of two forces—one her weight, or gravity, towards the earth, the other an undying impulse to fly off at a tangent, like a whirled stone when the sling is let go.

177. It was through the application partly of the laws of motion, and partly of Kepler's laws, that Newton established the universal prevalence of gravity. It being once found that the planetary motions could be kept up by a combination of forces; that is, by a force that projected the body once for all into free space with a great velocity, which, by the first law of motion, would be always kept up, whether it went off straight through space, or were compelled to go round a circle—and some second force to hold it in that circle; the great question arose, What is the *central* force—what power is it that causes the moon to fall towards the earth, instead of running off; and in like manner obliges the planets, with their immense speed, to keep constantly falling towards the sun? A planet P, if not held in by some tie, would fly off along PA, instead of being always carried round the sun S.



178. Newton proved by mathematical reasoning, from the *first* law of Kepler, that the deflecting force points exactly to the sun, and is therefore likely to be lodged in his body. From Kepler's *second* and *third* laws, he proved that the force is inversely as the square of the distance. And finally, he showed that the deflection of the moon from a straight line is exactly equal to the fall of a stone, if it were at the distance of the moon. The moon being 60 times farther off from the earth's centre than we are, gravity is there 3600 times weaker; so that the speed acquired by a stone falling one second on the earth, would be acquired only by falling an hour at the height of the moon. And it can be easily proved by calculation that the falling action of the moon is, in an hour, exactly that of a stone in a second. It being thus shown that the moon is deflected by gravity, it was then concluded that the planets are deflected to the sun by the same cause; or that gravity is the great *central* force throughout the solar system.

179. Newton also showed that gravity is a *mutual* action; or that it is not the moon falling to the earth, but the earth and moon moving towards each other. If the two were equal, they would approach at an equal rate; but the earth being the largest, its approach to the moon is by so much slower than the moon's approach to it. The consequence is, that in the revolution of the moon, the centre is, not the earth's centre, but the centre of gravity of the earth and the moon, or that point between them where they would be equally

balanced on a lever; so the sun, being attracted by all the planets, is not at rest, but is drawn about hither and thither; his enormous size preventing him from being moved very far. The centre of gravity of the solar system is not in the sun's centre, but near his surface.

180. After thus identifying the mechanical causes of the planetary motions, Newton deduced all the laws of Kepler from the combination of the two great forces of Gravitation and Straight Impulse. In this way he found that these laws are not strictly true as given by Kepler, and that therefore the prediction of the places from them could not be perfectly accurate. Not only was the sun's centre not the true focus of the ellipse, but he showed that not one of the paths is an exact ellipse or a perfect oval. If there were only one planet to the sun, that planet would describe a perfect ellipse; for it can be proved that if a body is projected in free space, under the action of the sun's gravity, it must move round the sun, either in a circle, an ellipse, or in one of the other figures of the conic sections (the parabola and hyperbola), and Kepler's laws will be strictly true, taking the centre of gravity as the centre of the motion. But if a second planet is introduced, this planet is not only attracted by the sun (and the sun attracted by it), but there is an attraction between it and the first planet which disturbs the motion of both; neither of them can in this case move in an exact ellipse. The more planets there are, the greater the mutual action, and the more they are liable to be disturbed in their elliptic courses.

181. In like manner, if the moon and the earth were alone in the universe, the moon would go round the common centre of gravity of the two in a perfect ellipse; but as both move round the sun, and he acts upon both, very great deviations take place from the elliptic orbit; in fact the application of Kepler's two first laws to the moon could never predict her place with anything like accuracy. The case is still worse with the satellites of Jupiter, which disturb one another, besides suffering disturbance from the attraction of the sun.

182. But the same discoveries that show the defects of Kepler's laws, give the means of correcting those defects, or of calculating the disturbing influences, so as to predict what the real motions will be under those disturbances. The whole series of these calculations make up the body of mechanical or physical astronomy. They require a constant use of the most intricate mathematical investigations, in consequence of the extreme complexity of the cases. All that we can do here is,

to state the manner in which the disturbing forces act, and the general consequences that arise from them.

MASSES OF THE HEAVENLY BODIES.

183. Under geometrical astronomy, we found it possible to measure the bulks of the bodies of the solar system; but we had no means of ascertaining their *masses*, which requires the bulk and density both to be known. But the theory of universal gravitation gives the means of supplying this particular, for the gravitating or attractive power of each body is as its entire mass; and if we can compare the attractive influences of two bodies, we can ascertain their relative quantities of matter. In the case of the moon revolving about the earth, or about the common centre of the two, if we could find how far each is from this centre, we could know the proportion of their weights as if they were weighed on a steelyard. Again, when a planet has a satellite, like the earth or Jupiter, the mass of the planet can be compared with the mass of the sun, by comparing the deflecting forces of the two, and allowing for the difference of distance. Thus the fall of the earth towards the sun in an hour, can be compared with the fall of the moon to the earth in an hour; and the two quantities multiplied by the squares of the two distances, will give the proportion between the mass of the sun and the mass of the earth, which is about 355,000 to 1. When we remember that the *bulk* of the sun exceeds that of the earth more than a million of times, we see that the matter of the sun is much lighter than the material of the earth. In the same way Jupiter's mass is found to be 340 times the earth, Saturn about 100 times the earth, Uranus 20 times. These bodies appear to be made of very much lighter material than our globe. The moon is $\frac{1}{80}$th of the earth.

184. When planets have no satellites, their mutual disturbing power must be calculated. Thus Mercury and Venus disturb one another's regular elliptic motion, and the amount of deviation of the one due to the action of the other shows the gravitating energy of each, or its mass. As we compare masses on the earth by their weights or gravities, so we compare the celestial masses by their attractive energy, making allowance for the effect of distance. In this way it is found that Venus is $\frac{9}{10}$ths of the earth, being nearly equal to it in this as in other respects. Mercury is $\frac{1}{6}$th of the earth, and by comparing this with its dimensions, it appears to be the densest body in the solar system.

185. The masses of the nine small planets have not been well

ascertained. The masses of the comets are entirely inappreciable, inasmuch as they have never been observed to exercise any disturbing influence upon the planets, even when passing very near them. It must therefore be inferred that they are made up of excessively light and thin material.

186. To find the actual density or specific gravity of the different bodies of the solar system, and compare it with a fixed standard, such as water, it is necessary to know the average density of the whole earth. This has been sought by comparing the attraction of some known body with the attraction of the globe, which last is the same as the *weight* of any substance. Thus Dr Maskelyne attempted to calculate the attraction of a mountain in Perthshire, by finding how far it made a plumb-line to deviate from the perpendicular. In this experiment the plumb-ball was supposed to be attracted downwards by the general mass of the earth, and sideways by the mountain; and the direction that it actually hung would therefore be between the two—partly down to the earth's centre, partly aside towards the body of the mountain; and the amount of its inclination to each would be the measure of their relative gravities. It could thus be seen how many times the whole earth surpassed the mountain in gravitating force. And if the mountain itself were measured, and its composition ascertained, so as to give the density of its rocky material, the entire mass of the mountain would be obtained, and from that the entire mass of the earth. The result of this experiment was, that the earth is, on an average, 5½ times denser than water, or more than twice the density of granite or sandstone rock. Another experiment, of a different kind, gave the same determination. From this we can estimate the densities of the sun, moon, planets, and satellites.

THE FIGURES OF THE HEAVENLY BODIES, VIEWED ON MECHANICAL PRINCIPLES.

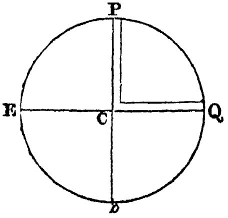
187. It is convenient to follow the same order in mechanical as in geometrical astronomy; to consider first the figures of the bodies themselves, and next the paths of their motions through space.

188. It has already been seen that the sun and planets are, in general, round masses, with a slight flattening, which seems to be connected with the rapidity of their whirl. Now both the general roundness and the flattening can be shown to arise from ordinary mechanical laws, such as we see operating on the earth, provided we suppose that the planets

were at one time soft fluid masses. If a fluid mass of attracting particles are left to themselves—that is, if there be no external compulsion, either attraction or pressure—they will always assume the *round* shape. Thus the drops of rain, and liquid drops in general, are nearly round; and they would be perfectly so if they were in free space, out of the reach of attracting bodies. On the same principle, a soft planetary mass, or a liquid satellite, would, by its own gravity, cohere into a round ball; so that the geometrical observation agrees exactly with the mechanical theory.

189. In the second place, the *flattening* is the consequence of the round balls being made to whirl, instead of remaining at rest. When a body is whirled, the matter at the surface acquires a tendency to fly off, so as to oppose the general attraction towards the centre. If the whirled body is soft or liquid, it cannot remain at rest, or in equilibrium, in its round form, inasmuch as the matter at the equator is rendered lighter by its centrifugal tendency, and is not a sufficient balance for the matter at the poles. To restore the balance, there must be a greater depth from the equator to the centre than from the poles to the centre; in other words, the equatorial width must exceed the polar width, which is what we actually find in all the revolving bodies. So that whereas a sphere is the *stable* form of a coherent mass at rest; a *spheroid*, or a flattened sphere, is the only stable form of a mass in rotation. It is the only form wherein the parts are so fairly balanced as to have no tendency to move out of their places; and the more rapid the whirl, the more is the equatorial portion lightened, and the higher it must rise, to compensate by quantity its loss of weight, and to sustain the pressure from the poles, which is not affected by the whirling motion.

190. Thus in the figure, let Pp be the axis which the planet whirls round; then the matter towards E and Q, by acquiring a tendency to fly off, presses less towards the centre than the matter about P and p, the poles: suppose a bent tube PCQ, having two connected columns mutually supporting one another; if the portion CQ is made lighter, it must rise so much higher, to be equal to the column CP, and to keep up the balance of the two. And what happens thus in any single column happens over the whole: a shorter mass from the pole to the centre suffices to balance a deeper mass from the equator to



the centre; the difference being the greater as the equatorial mass is lightened by increase of rotatory speed.

191. That the matter on the equatorial regions of a planet gravitates less than at the poles, is proved by experiments on the earth. Bodies are found to weigh less in tropical countries than in high latitudes. The fall of a stone is less rapid, and the swing of a pendulum is slower; all showing a diminished gravity.

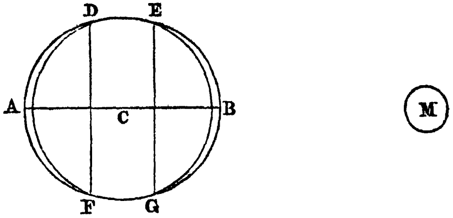
THE TIDES.

192. The tides are those regular movements of the sea whereby it rises and falls on its shores about twice a-day. They may be regarded as a slight disturbance of the figure of the earth. The methods of calculating them are similar to the investigations of the general question of the figure; hence they are regarded as a portion of the same subject.

193. It was observed before the time of Newton that the tides have some relation to the moon; that they rise highest about new and full moon, and least when the moon is in her quarters, or half full. But it was Newton who first showed them to be one of the many consequences of universal gravitation. In fact they are a perpetual disturbance of the liquid surface of the earth by the moon and the sun. It was stated above that a coherent body becomes perfectly round only if left free from external action. If there is an attraction on one side, the matter will be unduly drawn to that side, and the round figure will be disturbed. Thus if the moon had always stood over one place of the earth when it was in a soft state, the earth, instead of becoming round, would have been drawn out into an elongated mass, the long side being in the direction of the moon. If the moon stood still now, the *liquid* of the earth, or the general ocean, would be drawn more to some parts than others, and would remain permanently in that unequal state. But as the moon is continually shifting its position, partly by its daily and partly by its monthly motion, or partly by the earth's rotation and partly by the moon's monthly revolution, the water, as acted on by the lunar attraction, cannot always hold one position, but must shift as the moon shifts, and must run a course every lunar day—that is, between two returns of the moon to the meridian. This continual shifting keeps the water perpetually moving.

194. The constant tendency of the moon is to elevate the waters on the side of the earth that faces her for the time, and also on the side directly opposite to this; whence it follows that on all other parts they will be lowered. Its action

is to draw the earth out, or make it longer towards the moon, and narrower in the cross direction. Thus in the figure, let M be the moon, and the larger circle the earth; the moon's



action tends to keep up the water around B and around A, and to drain it off from the cross belt DEGF: it is not content with acting on the near side, so as to draw up the waters under itself, it disturbs the whole figure of the earth from one end to the other. This disturbance arises from its attraction being greater at the near surface than at the far, according to the law of gravitation; it attracts B at the near surface more than C at the centre, and for that reason raises B above its usual level; but it also attracts C at the centre more than A at the far surface, and therefore draws C away from A, or leaves A in some measure behind the centre, which causes it to rise likewise. If the moon's gravity acted equally on all parts of the earth, there would be no disturbance of the round figure, and no tides; but the inequality produces that general elongation which leaves the farthest-off parts as far behind the centre, as it draws the near parts before the centre; and the effect on both sides is the same—there is a diminished pressure and a rise of level at each, and the cross belt extending round between the two is so much depressed. By calculating this effect of the moon from her mass and her distance, it is found that she would sustain the water on the two ends *five* feet higher than the water on the transverse belt.

195. The sun is also capable of exerting a disturbing action of the same kind; but weaker than the moon's, in consequence of his immense distance, which more than takes off for the effect of his mass. By his attraction he raises the water about *two* feet.

196. But in the course of 6 hours the moon is a quarter round the earth, and at the end of that time she is drawing up the waters over the very places that she drew them away from at the beginning of it; thus reversing the process, and making what was high low, and what was low high. In

other 6 hours and a few minutes, she is over another quarter, and produces the same effects as she caused about 12 hours before: in the next half day she goes through the same changes, and in a whole lunar day she has caused two high tides and two low tides all over the earth. A lunar day is, on an average, 24 hours 54 minutes; so that the time from high-water to high-water again will be nearly 12½ hours; and in general the tides will seem to happen about an hour later every successive day.

197. But although the moon is the chief influence in ruling the tide, we must always allow for the sun's action. The sun may be supposed to make a tide of his own, of which there will be two every solar day. If this coincide with the moon's tide, the latter will be so much higher; it will be about 7 feet instead of 5: if the sun's tide is cross to the moon's, the latter (which will be the tide nevertheless) will be so much lower; it will be only about 3 feet. When the sun and moon are in conjunction, which happens at new moon, they will act in the same direction, and produce the combined tide, which is called the *spring-tide.* When they are in opposite sides of the earth, or at full moon, their tides will also conspire, and yield a spring-tide. At all other positions they will act in different directions; and when the moon is in her quarters the opposition will be greatest, and the tides will be least, or what is called *neap-tide.* But it is a general rule in all actions that require time, that the greatest effect does not happen till some time after the period of the greatest energy of the cause. Thus the greatest heat of the day is not at twelve o'clock, but between one and two. So high-water does not happen when the moon is in the meridian (or most directly over the place), but some time after; and in like manner spring-tides occur a day or two after new and full moon, and neap-tides after the moon has passed her quarters.

198. Tides are necessarily affected by the *declinations* of the sun or moon, or their distance from the equator. When the moon is in the celestial equator, she is directly opposite to the earth's equator, and the centre or extreme height of the tide will be on the equator. But if she has 5 degrees of north declination, she will be opposite to a place at 5 degrees of north latitude, and on this parallel will the centre of the tide lie, and at the equator the height will be somewhat less; so that the heights of the tide in any one place will vary as the sun and moon change their declinations, and put that place nearer or farther from the centre of the elevated water. Moreover, the coincidence of the sun and moon is not perfect, unless they have equal declinations, so that spring-tides will

themselves vary from month to month. When the sun and moon are so directly in a line with the earth as to make an eclipse, we have then the best possible combination for making a high tide. Allowing for the variation in declinations, the highest spring-tide will be to the lowest neap-tide as 10 to 3.

199. In particular places, the tide is very much affected by the nature of the coast, or the bed where it runs. If the water run into a channel which grows gradually narrower, it rises to a much greater height than the average. At Bristol the difference between low and high water is sometimes fifty feet. Tides are most regular in the great oceans, as in the Pacific. In the Mediterranean they are almost imperceptible, from its being so much isolated from the great seas, that the interval between low and high water is too short to allow the effect to be produced.

200. The atmosphere is subject to tides as well as the sea, which are made sensible by daily fluctuations of the barometer. (See METEOROLOGY.)

PERTURBATIONS OF THE MOTIONS OF THE HEAVENLY BODIES.

201. We have seen that the planets (including the earth) and their satellites have all two motions—a motion in an orbit, and a motion of rotation about an axis. These motions have both a mechanical explanation; the irregularities that they are subject to have also a mechanical explanation; and some of them even owe their first discovery to the following out of the mechanical laws and the theory of gravitation to all their consequences.

The Orbits and their Perturbations.

202. By mechanical reasoning, Newton showed that the planets, if undisturbed, would move in exact ellipses, and could be exactly calculated from the laws of Kepler; but in consequence of their mutual action they deviate from ellipses in many respects, and therefore cannot be predicted, unless the deviations are calculated by taking accurately into account the forces that produce them. Now to compute the effects of certain given forces is exactly a mechanical problem.

203. In studying the perturbations, astronomers first suppose the case of one body revolving about a second, and disturbed in its regular orbit by a third; this is what is called the *problem of the three bodies*. If the disturbing effect of each separate cause can be ascertained, it is easy to combine them so as to find the whole disturbance acting in any one

case. In the case of the moon, to us one of the most important bodies of the system, the main disturbing element is the sun; and we have to suppose the moon describing an elliptic orbit about the earth, which is perpetually altered by the action of the sun; so that the actual case is a case of three bodies.

204. In fixing the exact position and movements of any body, there are certain quantities that have to be accurately determined. These are called the *elements* of the body's orbit; and so long as it adheres to a perfect elliptical form, these are unaltered; but the smallest deviation will occasion a change in some one or more of them.

205. The elements of a planet's orbit are—

1st, The *mean distance*, which is the same as half the longer axis of the orbit.

2d, The *periodic time*, or the duration of a complete revolution.

3d, The *eccentricity*, which determines the proportion of the length of the orbit to its breadth, or the shape of the ellipse.

4th, The *inclination of the orbit* to some standard plane, such as the ecliptic. The plane of the orbit may sway backwards and forwards, so as to lie differently among the stars at different times.

5th, The *place of the nodes*; that is, the line of intersection of the plane of the orbit with the plane of the ecliptic. The inclination of the two planes may remain the same, and yet the one may so turn round on the other, that the line where they cut may lie sometimes one way, sometimes another. To fix this element, therefore, it is necessary to state the longitude of one of the nodes, or intersecting points. What is called the *ascending node* is chosen for this purpose; which means the intersection that the planet passes through in going from the south to the north side of the ecliptic. Since all over Europe, and most of the civilised part of the globe, the north pole of the heavens is above the horizon, it has become the practice to call the north side of the ecliptic or equinoctial *up*, and the south side *down*; as in maps, the head of the map is always the north. The passage of a planet from south to north is called, therefore, its *ascending passage*; and the distance on the ecliptic between this point and the vernal equinox is called the *longitude of the node*. Thus the longitude of Mercury's node at the beginning of this century was 45 degrees 57½ minutes.

6th, The *direction of the orbit*; that is, the direction of the longer axis. If the centre of movement be fixed, it will make a great difference in the place of the planet whether its ellipse runs out into one direction or into the opposite. This is settled by assigning the longitude of the point of the orbit nearest to the central body—called, in the case of a planet, the *perihelion;* in the case of the moon, the *perigee;* in the case of the satellites of Jupiter, the *perijove.* Thus the longitude of Mercury's perihelion at the beginning of the century was 74 degrees 21 minutes 47 seconds.

206. These six are the permanent elements of the body's revolution in its orbit. If these are all known, and if their rate of change in consequence of disturbance is known, it is only necessary to state whereabouts in its orbit a body was at some one time, to calculate where it will be at any future time. And it is our finding that some one of these six quantities is changed that is the proof of a disturbing action; for in the case of two bodies alone, one revolving around the other, none of the six would ever vary. A disturbing body is sometimes placed so as to affect one or two of them, and not the others; and the main point to be attended to in each case of perturbation, is to apply the doctrine of the resolution of forces, so as to find the effect upon each of the elements that are affected. Thus the effect of the sun on the moon is sometimes to increase her mean distance, and thereby increase her time of revolution (which are connected by Kepler's third law); at other times the opposite of this: again, it affects the eccentricity or shape of the orbit; it is almost always altering the inclination of the orbit either one way or other; the nodes are constantly shifted by its action, and the line of section of the orbit is made to wheel round steadily. In like manner the direction of the orbit is under continual disturbance.

207. The intricacy of the calculation of all these changes is owing to the constant variation of the disturbing force. If the disturbing body is approaching nearer, or going farther off, its action will be increasing or diminishing; so the direction wherein it acts is perpetually altering, from the movements of one or other of the bodies concerned. Now it is exceedingly difficult to calculate a week or a year's effect of a force that has been altering in its intensity every hour and minute, and also acting in varying directions.

208. The bodies that are least disturbed are the planets; next to these are the satellites; and the most disturbed of all are the comets.

Disturbances of the Orbits of the Planets.

209. The planets have certain peculiarities in their orbits, which save them from great disturbances. In the first place,

their eccentricities are very small—in fact, their orbits approach closely to circles; and this, by keeping them at an almost uniform distance from the sun, prevents their close encounter with one another, and nearly takes away the occasion of two classes of disturbances; namely, that of the eccentricity and that of the direction of the orbit. In the next place, they are nearly all in one plane, or they have no great inclinations to one another; whereby they have the less tendency to alter each other's inclinations. Of course if they were all *exactly* in one plane, as if they were rolling round over one wide level surface, their mutual attractions would never draw them out of that plane, or alter the way that their orbits lie among the stars. Being, however, in different planes, their disturbance in this matter is the less, from the inclinations being small.

210. A planet is most disturbed if it happen to have another planet as a close neighbour, and if that neighbour be large. But the immense preponderance of the sun prevents any planet from effecting a very great disturbance on another; because the action of the largest of the planets is trifling compared with the action of the sun, which keeps up the regular movement in an elliptic orbit. The perturbations that do occur are, moreover, *periodical*—that is, they go through regular courses, and at the end of a given period leave the elements as they were at the beginning. When these periods are very long, or extend to centuries, the perturbations are called *secular*. Taking the different elements of their orbits in order, we find in the case of the planets, first, that the mean distance and periodic time remain invariable, so that a planet's year is not shortened or lengthened, and it makes no progress in the way of falling into the sun, or going off into a wider orbit. Next in order of stability are the eccentricities and inclinations; and the variations of these never accumulate beyond a certain amount; that is, they go on so far increasing, and then begin to diminish, and keep up a constant average on the whole. There are greater variations in the direction of the line of intersection, or the place of the *nodes*, and also in the direction of the *orbit*, or the place of the perihelion; these have a slow steady revolution, so that in the course of centuries they describe the entire circle of the heavens.

211. When very long periods are taken, a remarkable compensation arises in the mutual disturbance of two neighbouring planets. There is a peculiar case of this balancing known by the name of *inequalities of long period*, which may be illustrated thus:—If one planet described a revolution in a year,

and another beyond it exactly in two years, there would be periodical conjunctions, happening in certain parts of the circle. In fact, supposing the planets to set out together from a conjunction, at the end of a year the inner planet would be round at the starting-place, and the outer planet would be half round, or in direct opposition. At the end of the second year, the inner planet would be round at the starting-place again, and the outer would also be there, and the two would be as they were two years ago. Now, in the course of these two years, they have been in every possible situation with respect to each other that could ever happen to them; for they would be always repeating the same course. Moreover, they would have gone through, as it were, a course of *opposite* positions. They would have been so long in conjunction, or on the same side of the sun, and in this position the outer would have drawn away the inner from the centre, and the inner would have made the outer to approach nearer; but they would be also at another time in opposition; and during this time some effects would arise exactly opposite to the previous. And every other situation would have another corresponding situation, where some of the effects of the first were neutralised; so that, at the end of two years, a portion of the disturbances would have arisen and disappeared, and left nothing to accumulate. Now there are no two planets whose periods are so simply related as 1 to 2; but there are simple relations among some of them, which cause a harmony of positions like the above, and at the end of certain intervals make them start together at the same points in the heavens. Thus the periodic time of Jupiter is to the periodic time of Saturn as 2 to 5, and more accurately as 29 to 72. In the course of 855 years Saturn will have gone round 29 times, and Jupiter 72 times; and in the course of this interval certain disturbances will have arisen, increased to a certain amount, then diminished and disappeared. For instance, during the first half the mean distance of Jupiter will go on slowly lessening, and that of Saturn slowly increasing; and during the second half the reverse will occur, so as to leave both distances at the end of the period as they were at the beginning, in so far as this particular disturbance is concerned. There are similar compensations in other pairs of adjoining planets, as in the case of Mercury and Venus, Venus and the earth, &c.

Disturbances of the Orbits of the Satellites.

212. A satellite must of course share in the irregularities of its primary; but this, though a cause of observable perturbations—in the moon, for instance—is a small matter com-

pared with the disturbing action of the sun. If the planet and satellite were always at the same distance from the sun, or if gravity did not vary with distance, the two would be at all times equally acted on by the latter, and there would be no disturbance in the orbit of the satellite about the planet. But the motion of the satellite throws it sometimes nearer, and at other times farther from the sun than the planet, and hence one is more acted on than the other; and from this difference, which is greatest at the conjunctions and oppositions, and gradually diminishes to nothing at the quadratures, all the disturbances arise.

213. So great are the disturbances of the moon, that to suppose her orbit elliptical and fixed, and calculate her motions by the laws of Kepler, would be so inaccurate as to serve no practical end. The first great inequality in her motion arises from the elliptic form of the earth's motion, whereby both earth and moon are nearer the sun at one time of the year than at another. The effect of this is, that the moon's motion is quickened as the earth passes from her greatest to her least distance from the sun, and rendered slower as the earth moves from the least distance to the greatest. This is called the *annual equation* of the moon. The greatest error in the moon's place arising from this is about $\frac{1}{6}$th of a degree, or a third of her breadth.

214. A second inequality is that termed the *variation*, or the increase and diminution of velocity, that take place alternately in the course of a single revolution, or between two new moons. Undisturbed by the sun, the velocity of the moon would vary in a fixed proportion to her distance by the first law of Kepler; but it is one of the effects of the sun's attraction to diminish the velocity in the first quarter, increase it in the second, diminish it in the third, and increase it again in the fourth: so that her actual place will be, now before and now behind, what it would be by Kepler's law. The error from this cause mounts up to 32 minutes, or about the moon's whole breadth.

215. The first inequality above-mentioned depends on the earth's place in her orbit; the second on the moon's place in her orbit in reference to the sun. There is a third inequality resulting from the eccentricity of the moon's orbit, or which would not exist if she moved in a circle. The sun's action on the ellipse that the moon describes, is to make it, as it were, whirl round bodily, or to make its longer axis go round slowly in a circle. Every month this line moves forward by a certain angle, sometimes more, and sometimes less, according to its position; and it accomplishes an entire revolution in

about nine years. The irregularity of this movement is very great; for although it is on the whole progressive—that is, in the direction of the moon's own motion—it is sometimes going backwards for months together. The consequence of the movement is, that the places of the moon's least and greatest distances from the earth (*Perigee* and *Apogee*) are not permanent, but lie in every direction in the course of nine years.

216. The eccentricity of the moon's orbit, which gives rise to this change of its direction, is itself disturbed in consequence—being sometimes above and sometimes below the average, to the extent of ⅕th of the whole. When the long axis of the orbit points to the sun, the eccentricity is greatest; when the short axis points to the sun, it is least. This change of eccentricity does not alter the mean distance of the moon from the earth, but it alters her greatest and least distances.

217. All these inequalities would take place though sun, earth, and moon were in the same level plane; but as the moon is sometimes on one side of the plane of the earth's orbit (the ecliptic), and sometimes on the other, she is liable to be disturbed in this particular. Instead of keeping always in her own plane, she is liable to be drawn out of it, so as to be sometimes less, and sometimes more inclined to the ecliptic. Her average inclination is about 5 degrees—a comparatively small quantity. A double effect arises from the sun's action on this inclination. In the first place, there is a steady revolution of the line of nodes, or the line of section of the moon's plane and the ecliptic, so that her places of crossing the ecliptic are continually shifting. This motion is backwards, or in opposition to the moon's course. If we suppose her crossing through the ecliptic at a certain place, rising above it, going round half a circle, and coming to cross again to go to the other side of the ecliptic, we find that, instead of having gone over an entire half circle before reaching the ecliptic, she crosses before she has gone so far; and then, on proceeding round to the ascending node which we supposed her to start from, she crosses again very much behind her previous crossing. Between one node and the opposite there is less than 180 degrees; and between two successive nodes there is less than a circle. The retreat of the crossing points takes place at such a rate on the whole, that it completes its backward circle in nineteen years. This is a period very important in the calculation of eclipses, as they occur in nearly the same series in every revolution of the nodes. In the second place, the inclination itself fluctuates to the extent of about 8 minutes.

218. The disturbances of the satellites of Jupiter and Saturn are naturally more complicated than those of the moon, from their action on one another being added to the disturbing influence of the sun. Their mutual action, however, becomes simplified on the principle of compensation by opposite positions; and certain very simple laws have been discovered in the motions of the satellites of Jupiter, which assist in predicting their eclipses. The system of Saturn is very complicated, from the existence of seven satellites, besides a double ring whirling whole about the body of the planet.

Disturbances of the Orbits of the Comets.

219. The comets have certain peculiarities in their orbits, that render these liable to a greater degree of disturbance than either planets or moons. Their orbits have very large eccentricities—that is, they have a long and narrow shape; they have also frequently very great inclinations to the ecliptic region, to which the rest of the solar system is confined. Hence the dimensions of their path, and its direction in the heavens, are subject to very great alterations, which it is exceedingly difficult to compute. Accordingly, the prediction of the return of comets is as yet very imperfectly effected. Their masses also seem to fluctuate. They are so rare, and so much spread out, that they would appear liable to be absorbed by the sun as they pass their perihelion. Halley's comet, which revolves in about seventy-five years, had its last return predicted by calculating its perturbations by the several planets that would be near enough to affect it; and it did actually return, and passed its perihelion in November 1835, within a few days of the assigned date.

PERTURBATIONS OF THE ROTATIONS OF THE HEAVENLY BODIES.

220. The mechanical theory of a planet's undisturbed rotation is very simple. A body, once set a-whirling, will go on to whirl for ever at the same uniform rate, by the first law of motion; so that, if we ascertain the time of one whirl, we can predict its future positions at any time. Whence, on mechanical principles, the rotation of the planets ought to be uniform; and this we find is actually the case. The daily rotation of the earth produces the apparent daily revolution of the starry sphere, and measures the sidereal day, which has preserved the same length through all the experience of the human race; so that there is evidently no cause existing to disturb the natural tendency of such motions to persevere.

221. We have seen also that the flattening of the planets has a simple mechanical explanation. But this flattening at the poles, and bulging at the equator, exposes them to a disturbance, which, though it does not affect their rotatory speed, alters the direction of their axes, so that these point, now to one place in the stars, and afterwards to another. The earth suffers an irregularity that is traceable to its equatorial bulging. The first part of this irregularity is the *precession of the equinoxes*, or the retreat of the points where the ecliptic cuts the equator. The celestial equator is marked out by the terrestrial equator; and if the latter change its place, by the earth whirling in some new direction, the places of the equator and poles of the heavens among the stars will be changed. On the ecliptic, precession is observed by the retreat of the equinoxes; the retreat of the equinoxes or nodes is accompanied by a change in the celestial pole, whereby it revolves in a circle in the heavens round the more fixed pole of the ecliptic. The origin of the whole effect is the action of the moon and sun upon the equatorial bulging of the earth. If the earth were a perfect sphere, her position on her axis would not be changed by any foreign attraction; but the ring of equatorial matter is disturbed as if it were a satellite going round the earth, only in its disturbances it has to drag the whole mass of the earth along with it; and hence the amount of variation becomes very much less than a detached satellite or ring would suffer. The disturbance actually arising is the same in character as the disturbance in the moon's orbit arising from its inclination; it is a retreat of the nodes, or of the intersection of the earth's equator on the plane of the ecliptic, or the plane of its annual revolution. This retreat being 50 seconds a year, the entire period of the revolution of the equinoxes is about 26,000 years. In this time the celestial pole describes a circle among the stars, whose radius is the obliquity of the ecliptic. The motion of the earth, in this case, is like an inclined spinning top, which keeps up the same slant, while it whirls round so as to describe a conical figure with its axis. As in the case of the tides, the sun and moon conspire to create this disturbance.

222. There is a secondary disturbance added to the precession, called the *nutation* of the earth's axis, which causes a fluctuation in the motion of the nodes of a short period. The moon being the great disturbing agency in causing precession, her tendency is to make the nodes have their regular retreat only on *her own plane*, not on that of the ecliptic. Now as the moon's plane itself retreats on the ecliptic, so as to go round in nineteen years, the actual precession is a combined pheno-

menon; and the second part shows itself in the earth's axis, describing every nineteen years a very small ellipse (18½ seconds by 13¾ seconds) among the stars, while moving on in its large circle of precession. In settling the first point of Aries, in order to fix the starting-point of right ascensions and longitudes, the nutation must be considered as well as the precession; and these two may be considered as making the *fourth* great *correction*, to be applied to celestial observations, after allowing for refraction, parallax, and aberration.

STABILITY OF THE SYSTEM.

223. It is natural to inquire whether the numerous perturbations which all the bodies are subject to, are such as in the longrun to overthrow the present arrangements of the system. If any cause were at work to diminish steadily the mean distance of a planet, it must of course ultimately fall into the sun. It has, however, been proved that the total effect of all the mutual disturbances has no such tendency, and that the planets and satellites may revolve for countless ages without any radical change happening to the character of their orbits; they will preserve both their mean distances and the average shape of their ellipses. The only thing that can bring about a decay in the system is a resisting medium—that is, if the planetary spaces, instead of being perfectly blank and void, are filled with a very thin gas or ether that would impede the motion of bodies, as our own atmosphere resists any body that is impelled through it. It is at present doubtful if such an ether exists; it is certain that, if it does exist, it is exceedingly rare, and cannot produce any perceptible effect in less than thousands of years; still, if it exist at all, it will tell some time or other, and will have the effect of lessening the mean distances, and contracting the orbits, so that an end to planetary revolution must be the inevitable consequence.

224. It has been suggested, on the other hand, as probable that the planetary periods may continue to diminish for thousands of years yet to come, then reach a limit, and afterwards gradually return to their former periods of revolution. This progressive and retrograde, or oscillatory kind of motion, is by no means uncommon in nature, a noted example being found in the magnetic needle, which seems to oscillate between 23 degrees west and 23 degrees east of due north in the course of several hundred years. It is expected that the question of a medium will be decided, from a study of the comets, which are so light, and so much spread out, that a very slight resistance would soon show itself in contracting their orbits.

SIDEREAL ASTRONOMY.

225. Although the solar system, with all its extent and grandeur, is a mere handbreadth and a few atoms compared with the starry universe, yet our knowledge of the latter is very slender compared with the complete information we possess of the former. The first thing that strikes us about the stars is their difference of brightness. They can be classified according to this feature. The most brilliant are said to be of the first magnitude; the next of the second; and so on: the smallest that are usually seen by the naked eye are generally of the fifth magnitude. By using telescopes, a vast mass of new stars come into view, which are reckoned as far as the sixteenth magnitude; the numbers and closeness increasing with every increase of the telescope's power.

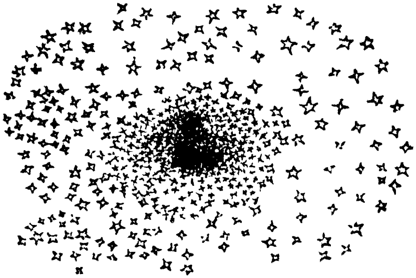
226. The stars are very unequally scattered over the sky. We may always observe a whitish band arching the heavens, called the Milky Way, which appears to the eye, and still more to the telescope, as a dense mass of starry dust; in other words, an infinite host of stars, whose vast distances can be neither measured nor imagined.

227. Since the stars have been closely watched, some of them have been discovered to vary in their appearance at different times. A few of them have come to be called *periodical stars,* from their going through a regular change of brightness, like the moon. At one time they will be of the second, third, or fourth magnitude, and at another time very much less, or they may even disappear entirely. The periods of this change have in several cases been determined. But there are stars that appear suddenly, and disappear suddenly, according to no known law.

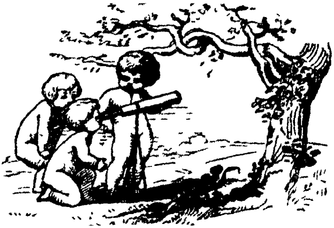
228. Another remarkable class of stars are the *double stars,* so called, not from lying beside each other merely, but from their being seen to revolve about one another in regular periods. Many hundreds of these systems have been observed; a good many have had their periodic times determined, as well as the apparent size of their ellipses. Some of the periods extend to several hundreds of years.

229. Another set of peculiar objects is the *nebulæ,* or hazy patches of faint light, like a thin flame. When telescopes of high powers were applied to these, many of them resolved themselves into crowds of stars. (See fig.) But there were others that could not be thus resolved, and had such a peculiar appearance, that it was thought by Sir William Herschel that

they were not starry masses, but patches of diffused matter, in the course of being condensed into stars. It was believed by



many people that such uncondensed suns were likely to exist; but the application of the powerful telescope of Lord Rosse showed, in 1846, that one of the most marked of these nebulæ (the nebula in Orion) did really consist of an immense irregular mass of stars, undiscernible before, from its being situated so remote in the depths of the starry spaces that the separate stars could not be seen. These nebulæ are scattered over the heavens in great numbers; and they give us the idea of infinite space being filled with innumerable clusters of stars scattered here and there at vast intervals, and every cluster composed of millions upon millions of individual suns, whose mutual distances even are beyond the power of our imagination to conjecture.



NATURAL PHILOSOPHY.

SEVENTH TREATISE.

ELECTRICITY.

Edinburgh :
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NOTICE.

Electricity is the branch of Natural Philosophy most closely allied to Chemistry. Hence, although in the order of study Chemistry comes after Natural Philosophy, a certain acquaintance with the primary facts of Chemistry will be of use in facilitating the comprehension of some portions of the present subject, particularly Voltaic Electricity. Before entering upon that department, the teacher will find it advantageous to state, and illustrate by a few familiar examples, the nature of chemical combination and decomposition, and to distinguish these from mixtures and separations that are not chemical. The leading properties of chemical union are the fixed proportions of the combining substances, the giving out of heat (as in burning), and the total difference between the resulting compound and either of the individuals in their whole aspect and properties. Thus a certain weight of sulphur, combining with a fixed proportion of copper filings, will produce heat while the union is going on, and will turn into a black substance in which neither copper nor sulphur could be recognised, and which could not serve any one of the special purposes of either.

In this, as in the preceding Treatises, great pains have been taken to render the arrangement as perspicuous, and the language as simple and intelligible, as the subject would allow.

Alex. Bain.

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oppose different points to the atoms next it, but the new points would repel in exactly the same manner as the old.

2. But nature makes use of forces that have not the unvarying character either of gravity, liquid cohesion, or gaseous repulsion. We find a kind of force inhering in atoms and masses of matter that is repulsive at one side of each atom or mass, and attractive at the opposite side. If we have two bodies adhering to one another by this force, and if we take one of them and turn it about so as to place the opposite end next the other, there will be no attraction; on the contrary, there will be a repulsion, and this repulsion will probably have the same strength that the previous attraction had. In this case, therefore, the mutual position of the bodies is an essential circumstance. Each mass has its power gathered into its ends, but the ends have contrary actions. If the forces on two opposite points were joined together, they would neutralise each other, and cause perfect indifference on the whole. To forces of this character the name POLAR is given; and bodies actuated by them are called polar, or polarised, or are said to have the attribute of polarity.

3. When bodies are crystallised, the force by which their atoms adhere is a polar force. An atom of ice will not adhere to another atom on any side; a certain point of the one clings to a certain point of the other; and if one of a pair of adjoining atoms were to have its ends reversed, the two atoms would repel one another violently. Hence crystallised bodies cannot have their particles stirred about like a liquid, or like red-hot iron; the least disturbance causes a fracture. If a particle is moved from its proper position, it either ceases to attract or it becomes repulsive, and there is an end to the cohesion. The property of *brittleness* generally indicates a polar cohesion. Malleability and ductility, or mobility of parts, show that the cohesion is not polar, but general, and evenly distributed over the entire surface of the particles. When bodies are at their highest pitch of solidity, hardness, or compactness of structure, they have generally the polar cohesion. This cohesion is uniformly destroyed by heat, which softens, melts, and finally evaporates solid substances. And in many other cases besides crystalline cohesion, heat is the destroyer of polarity.

4. Throughout the whole range of actions that are included under ELECTRICITY, polarity is an invariable characteristic. It is not possible to produce an electrical attraction without an equal repulsive power conjoined. Every electrified body is attractive at one end and repulsive at the other, or is polarised, like an atom of a crystal. It is in electricity that we can most completely study the nature and laws of polar force,

for there we have it under the greatest variety of different circumstances and modes. It is not confined to electricity; we see it also in light. Chemical forces have certainly a polar nature, and some of the vital forces appear to have the same character. Whether all the polar forces arise from one identical agency or from many, they at least serve to illustrate and explain each other; and the electrical phenomena present the most visible and tangible instances of the polar mode of action.

5. The word "electricity," taken from the Greek name for *amber* (which strongly exhibits the phenomena when rubbed), was at first applied to the electrifying of bodies by rubbing or friction; but it is now the general name for seven different kinds of electrical excitement. These seven kinds fall under two heads. When the excitement is in a state of repose, and maintains itself, it is called STATICAL ELECTRICITY; when the excitement is in a constant current, and requires to be continually renewed, it is called CURRENT ELECTRICITY. The subdivisions of each are as follow:—

STATICAL ELECTRICITY.

1. Magnetism.
2. Frictional or Tension Electricity.

CURRENT ELECTRICITY.

3. Voltaic Electricity.
4. Electro-Magnetism.
5. Magneto-Electricity.
6. Thermo-Electricity.
7. Animal Electricity.

MAGNETISM.

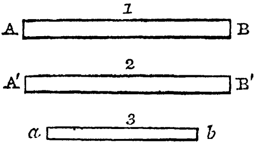
6. There is a certain ore of iron (an oxide, or a combination of the metal with oxygen) that has the property of attracting pieces of iron, and of communicating its attractive power to bars of steel. This ore is called the *loadstone*. The name *magnet*, also applied to it and to the bars of steel that have acquired its properties, is supposed to be derived from Magnesia, a country in Asia Minor, where it was first discovered.

LAWS OF MAGNETIC PHENOMENA.

7. The first principle of the magnetic force may be stated thus: *The magnet has always two poles or points where the power seems concentrated.* If we dip a magnetic bar into iron filings, on lifting it up we find a considerable quantity of the filings adhering to it, in consequence of its attraction for iron. On observing it closely, we see that the greatest mass of filings is attached to the two ends, that there is a gradual decrease towards the middle, and that in the middle point itself there is none. Hence it is said that the poles, or centres of the force, lie in the ends of the bar. A heavier piece of iron will be suspended at one of the ends than in any other place. The actual poles or points of highest concentration in the case of a bar, are each in the interior of the bar at a small distance, probably from a quarter of an inch to an inch from the extremities. Whatever be the shape of the magnetic mass, two such centres will be found in it. If a loadstone, or a steel magnet, is broken in two, each fragment will have two poles the same as the entire body; and this would hold if it were broken into any number of pieces. The poles are not of themselves the sources of the power. They resemble rather the centre of gravity of a body; which is the point, not where the gravity is actually lodged, but where, if it were lodged, the action of the body would continue the same; and which is continually changing with the changes of shape or contents that the body undergoes. The magnetic poles represent the total magnetism of the mass; when we speak of a body's distance from the magnet, we measure this distance from a pole. As a gravitating mass is a collection of gravitating atoms, so a magnet is a collection of magnetic atoms, each with its two poles; and when the forces of all the atoms are joined together, the result is the same as if the magnet were only a pair of atoms, placed

asunder at the distance of the two poles, and possessing opposite attractions.

8. *Magnets repel each other by their like poles, and attract each other by their unlike poles.* The two poles of a magnet, as of all polarised bodies, have opposite actions; what the one will attract, the other will repel, and what the one will repel, the other will attract. If we have two different magnets, and if we take a third magnet to try their action upon, we shall find out which is the like, and which the unlike poles. Present one end of the first to one end of the third; and suppose we find that they attract each other. Present next one end of the second to the same end of the third; if an attraction now takes place, the poles of the first and second that have thus shown a common attraction for one pole of the third, are *like* poles; they have both precisely the same action on one object. Their other ends, if tried in the same way, would show an identical action on the common object, and would also be like poles. But if a pole of the first attracted, and a pole of the second repelled, the same pole of the third, the poles of the first and second thus tried would be unlike poles. Thus, in the figure, suppose that the pole A of No. 1 attracted the end *b* of No. 3, and the pole A′ of No. 2 also attracted *b*, A and A′ are like poles; but if, while A attracted *b*, A′ repelled it, A and A′ would be unlike poles. Now, from the nature of polarity, the two poles of the same magnet are always unlike; that is, if A attracted *b*, B would repel *b*. By reversing the acting magnet while the magnet acted on remains, we get an opposite action.



9. Supposing, therefore, it is found by such a trial that A and A′ are the like poles of two magnets. Let us bring these two poles together, and the action is repulsion. So, if we bring the other ends together, B and B′, which also are like poles, they will repel each other. But if we bring A and B′ together, which are the unlike poles of the two magnets, they will attract each other, and adhere with more or less force according to their strength. The same will happen if we bring A′ and B together. And if, in the trial of the two first upon the third, it appeared that A and A′ attracted *b*, this would be a proof that the pole *b* was unlike the poles A and A′, and like their opposites B and B′; and that *a* is the pole like to A and A′.

10. The two poles of a magnet are distinguished by the

names North and South, from the north and south poles of the earth. The end of a magnetised needle or bar that points to the north pole of the earth when suspended freely, was at an early period termed the north pole, and the opposite end the south pole. This usage still continues, although erroneous. In fact, the end that is attracted to the north is, for that very reason, *unlike* the north magnetic pole of the earth, and ought to have been termed the south pole of the magnet.

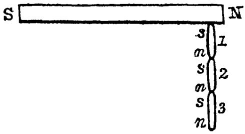
11. It thus appears that there exists within each magnet two contrary influences, which repel each other, and, through this repulsion, are distributed into the two farthest ends of the mass. Half-way between the poles is the cross line of neutrality. It is the place where the two opposing forces balance one another, and prevent an attraction taking place either way. We must regard the force even at one of the poles as a difference of two forces; for when a needle is attracted to the north pole of the magnet, it is under the repulsion of the south pole at the same instant. It is kept to the north pole only because it is nearest; for the magnetic force diminishes by distance. It is from the neutral line being equally distant from both poles that its neutrality arises. An object placed there is like the matter in the earth's centre, which, being equally attracted on all sides, shows no tendency to any.

12. *The attraction of magnets for unmagnetised iron arises from a temporary communication of magnetism, called induction.* If we bring a few iron filings or pieces of soft iron near the pole of the magnet, they will be attracted; if we take them off, and apply them to the other end, they will still be attracted. This at first sight appears to contradict the general statement as to the contrary nature of the two poles. But on nearer examination, it becomes perfectly consistent; and a new property of magnetism is disclosed by it. When we bring one end of a piece of soft iron near the pole of the magnet, the soft iron is itself rendered magnetic. Each magnet is, as it were, surrounded with an atmosphere that communicates the power to all iron masses that approach it. This temporary magnetism is always arranged in opposition to the forces of the principal magnet. The end of the soft bar touching the north pole of the magnet becomes a south pole; and the other end is a north pole, as may be seen by bringing the south pole of another magnet near it. While in actual contact with the magnet, the iron is not indifferent; if we try the remote end by a pole like the one that attracts the near end, we will see an active repulsion: so that a magnet attracts iron because it has the power of making it a magnet

for the time. The iron in contact is rendered polar throughout, and has this polarity concentrated in two opposite poles exactly like the loadstone. A magnet cannot attract silver, because it has not the power of imparting the magnetic state to atoms or masses of silver. Iron seems by nature susceptible of magnetism, and when once it is magnetised, it can attract other iron by magnetising it in turn.

13. The existence of this temporary influence, called *magnetic induction*, proves that polar bodies attract none but polar bodies. When a neutral body is brought near a polar body, there will be no action unless the neutral body is first polarised by the neighbourhood of the other.

14. When a magnet suspends iron filings, they may be seen hanging from it in threads, clinging not all to the magnet, but to one another in a chain. This action is best understood by taking a few iron balls or little bits of wire, and suspending one of them to a pole of the magnet. By this suspension it is made a magnet for the time, and two active poles are developed in it. If the north pole of the magnet is used, the wire 1 will have its upper end a south pole, and its lower end a north pole, ready to attract iron, as if it were a permanent loadstone. Bring now the wire 2 into contact with the first. The active north pole of No. 1 will develop an active south pole in the upper end of No. 2, and an active north pole at its lower end; the unlike poles will attract each other, and the second will hang by the first, and will have the power of communicating the same polarity, and exercising the same attraction for a third wire. The weight of wires that can be polarised and suspended is limited by the power of the magnet. As the lower end of the above series is a north pole, it may be carried across to the other end of the magnet which is south, and there attracted; and we will thus have a chain hanging from end to end of the magnet, each joining presenting a pair of opposite poles. The inductive strength of the two ends being combined in this case, a greater weight will be sustained than could be borne by a single pole.



15. We must conceive the atoms composing the magnet itself as exercising the same inductive power on one another, and in this way combining their strength together. But for this power which each little magnet has to throw its strength, as it were, into an adjoining magnet, there could be no accumulation of force. A chain never can be stronger than its

weakest link; and the end of a line of magnetic atoms would have no greater strength than a single atom unless each atom was heightened by the inductive force of the whole series. No. 1 has of itself a certain degree of polarity; No. 2 has in like manner a certain independent strength; when the two go together, the first adds its inductive strength to the natural polarity of the second, and the second does the same to the first, and each is now so much stronger than before. It is like the lowest stratum of a fluid which presses not only with its own gravity, but also with the accumulated gravity of all that lie above it.

16. *The power of the original magnet is exalted by the induction.* By connecting the two ends of a magnet by a rod of unmagnetised iron, the latter becomes magnetic under the induction, and seems to react upon the magnet by its induction, so as to maintain, and even to increase, its polarity. Left to itself, with its poles unconnected, a magnet's power gradually decays. The series of inductive polarities must form a circle to acquire the highest degree of intensity; and when an unmagnetic bar joins the poles, the exercise of the induction upon the fresh matter gradually heightens the sum of the polarity.

MAGNETS.

17. *The loadstone* has been termed the natural magnet, because it seems to have magnetism permanently engrained in its constitution. It is found in all parts of the world, and sometimes forms rocks of considerable size. Its strength is very unequal in different specimens. As a general rule, a small loadstone will carry a greater weight in proportion to its size than a large one. It has a grayish colour and a dark metallic lustre. Although an oxide of iron, it is not identical either with rust or with the scales of iron formed by burning iron wire in oxygen gas.

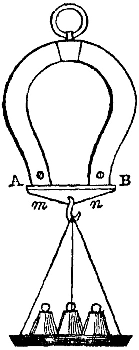
18. Artificial magnets are formed from bars of well-tempered steel. The instantaneous influence of a magnet on a steel bar is not so great as on soft iron, but the steel retains the polarity that has once been communicated to it. To magnetise the steel thoroughly, motion and friction are used. In general, if we take a loadstone, or a bar already magnetised, and rub one end along a steel bar repeatedly, and always in one direction, the steel bar will become magnetic; but in order to make the process effective, a mode of action must be used that uniformly tends to give one kind of magnetism to the bar—that is, that always developes the same pole at the

same end. If one part of the stroke tends to give a south pole, and another a north, to one end of the bar, the contradiction will destroy the effect. In rubbing a bar with a magnet, we ought to commence at the middle of the bar, and rub from thence to one end with one of the poles of the magnet; the magnet should then be reversed, and placed at the middle as before, and rubbed towards the other end of the bar. And the process should be repeated in the same order; one end of the magnet always going out to one end of the bar, and the other end of the magnet to the other end of the bar alternately. The bar will then be magnetised in such a manner that each end will be opposite to the end of the magnet that rubbed it. The same inductive action that renders soft iron temporarily magnetic by mere contact, comes into play here; but steel offers more resistance to the action than iron, and the friction is needed to overcome the resistance. The magnetic state thus forcibly communicated remains permanently in the steel bar, which has thenceforth the character of the natural loadstone.

19. In practice, it is found best to use two magnets to rub with, and thereby to perform both the rubbings at once. Opposite ends of the two rubbing magnets are laid together on the middle of the bar to be magnetised, and they are held so as to make a small angle with the bar; they are then drawn along, one to one end, and the other to the other end, repeatedly. The bar itself is laid in a straight line with two other magnets, which exert upon it the inductive contact while it undergoes the friction of the rubbing magnets. This method is found very suitable in magnetising needles for compasses. Another method, called the *double touch*, consists in arranging the bar as before, with magnets in a line with each end, and using two rubbing magnets with opposite poles brought together; but instead of beginning at the middle of the bar, and separating the two, and drawing them apart to the two ends, they are held together and rubbed from end to end backwards and forwards. The inclination in this case is to be still smaller than before. The ends of the rubbing magnets are not in actual contact, but press upon a wedge of wood or brass which lies between them. This method communicates a very intense degree of magnetism; but is apt to make the poles of the bar unequal in strength.

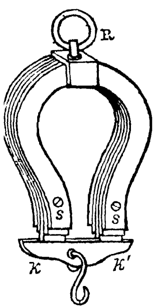
20. Instead of being a straight bar, it is convenient to give magnets the form of a horse-shoe, which brings their poles near each other, and makes it easy to complete the circle, and to bring both poles into play upon the same object. Such a magnet is represented in the following figure. A and B are

the two poles; they are joined by the bar *mn*, which is of course polarised; *m* having the opposite magnetism from A, and *n* from B. Each horse-shoe magnet is permanently furnished with such a cross-piece, made of soft iron, which is called the *keeper*, and sometimes the *lifter*, and also the *armature*. When the magnet is used to suspend weights, these are attached to the keeper, as shown in the figure.



21. In order to make a very powerful magnet, a number of single bars are joined together. This makes a *compound magnet*, or a magnetic bundle or battery. They may be either straight or horse-shoe bars. A compound horse-shoe magnet is represented beneath: R is the ring for suspending it, and *kk'* the armature; the bars are magnetised before being joined, and they are fastened by screws *s* and *s* running through them.

22. A piece of loadstone is generally fitted up in a framework of soft iron, and its poles are thus communicated to projecting ends of iron, which have the same action as the ends of magnetic bars.



23. The strength of a magnet may be gradually heightened by hanging weights to it, which are to be increased at intervals of time by little and little. On the other hand, the magnet is weakened by abruptly breaking the contact, as in drawing off the keeper suddenly. If an iron bar is in inductive contact with a magnet, and in that position receives a succession of blows with a hammer, it will acquire a fixed magnetism: so, if it is placed under induction while hot, and allowed to cool, the magnetic state will be confirmed so as to remain; also if iron, while under induction, becomes rusty, the chemical action will have the same effect in fixing the magnetism. On the principle that a change in the molecular constitution of the iron can render permanent the magnetic state, it is possible to form an artificial loadstone. On dipping a powerful horse-shoe magnet into iron filings, a great mass will be aggregated round each pole, and they will run together so as to make a string or tuft between the poles. The whole mass taken together will be as one magnet of loose cohesion. If the filings are then moistened with oil, and exposed to a

red heat while connected with the magnet, a partial oxidation of the iron will take place. The mass will then cohere together with some degree of compactness, and will remain permanently magnetic, and very much resemble the natural loadstone. On the other hand, a magnet when heated to redness and then cooled, loses its magnetism entirely, as well as its steel temper. Red-hot iron loses the power of being attracted by the magnet, and seems to become like one of the indifferent metals. On closer examination, however, and by the use of a magnet of very great power, Faraday found that the magnetic susceptibility is not entirely lost at a red heat, but merely very much enfeebled.

24. Iron is not the only magnetic metal, although it be the one most powerfully affected. Nickel and cobalt are also magnetic, and are attracted and polarised exactly like iron. It was formerly supposed that all the metals might be subject to magnetism in some degree, although perhaps it might require a much lower temperature than ordinary to make the polarity appear; but the recent experiments of Faraday are tending to show that only a limited number of them are magnetic; namely, the three already decided on--iron, nickel, and cobalt; and as far as appears at present, six others—titanium, manganese, cerium, chromium, palladium, and platinum. To these nine bodies must now be added OXYGEN, which Faraday has still more recently shown to be magnetic.

25. A certain number of metals when under high magnetic influence—as when lying between the poles of a powerful horse-shoe magnet—are repelled by both poles alike, so that a bar suspended between two poles is compelled to assume a cross position, from its seeking to be removed as far as it can be from both. To this action Faraday has given the name of *diamagnetism*, or cross magnetism. It is, however, radically different from magnetic action, although caused by a magnet. Its want of the polar character makes it an exception to all forms of electrical excitement. It takes place so decidedly on the following metals, as to prove them to be at least not magnetic—antimony, bismuth, cadmium, copper, gold, lead, mercury, silver, tin, zinc. But the cross action is not confined to metals: it belongs to almost all solid, liquid, and gaseous substances, excepting those that are magnetic; and it may belong to them too for anything we know, since, though it did exist, it would be overpowered and hidden by their magnetic tendency. The diamagnetic action is found to be strongest with bismuth, phosphorus, and the heavy glass, composed of silicated borate of lead.

26. When a substance is magnetic, like iron, all its com-

pounds are magnetic likewise. Oxides and salts, and the other combinations of iron, nickel, cobalt, titanium, &c. are all attracted by the magnet, and consequently excluded from the list of Faraday's diamagnetics. Liquid solutions of the acids and salts of these metals are seen to be magnetic as well as the solid masses. Hence if any compound of a metal shows polarity, or is attracted by a magnet, that metal is inferred to be magnetic. It was principally by the use of compounds that Faraday determined the magnetic character of the six metals above enumerated additional to iron, nickel, and cobalt. The magnetism of oxygen, however, is not maintained in its compounds.

MAGNETISM OF THE EARTH.

27. The earth, taken as a whole, forms a great magnet having two poles, termed its *north and south magnetic poles*. This is proved by the fact, that all magnets assume a fixed position on its surface, in a direction nearly north and south. If we suspend a magnetised bar with a string, and leave it to itself, on coming to rest it will take this north and south direction; and if we move it or whirl it round, it will come to rest again in the same position. The exact direction of the magnetic needle, or freely-suspended bar, in any place on the earth, determines the *magnetic meridian* of that place; which is an imaginary upright plane (like those used in astronomy), passing through or along the bar thus suspended. This meridian is not always due north and south, and consequently it does not coincide with the astronomical meridian. Its deviation from the latter is called the *declination*. This declination is sometimes east and sometimes west. It is also called the variation of the compass; and in using a compass to determine the true north point, allowance must be made for such variation.

28. The declination varies in different places, and is constantly changing for any one place. Its change is steady and progressive: after increasing up to a certain point on one side, it decreases, comes to nothing, and passes to the other side, where it increases to a maximum, and then commences to retreat. Thus in 1660 there was no variation in London; the needle lay exactly north and south. In 1700 it had acquired nearly 10 degrees of deviation to the west, which went on increasing in this direction during the whole of last century; and in 1800 it amounted to upwards of 24 degrees. From 1815 downwards it has been slowly decreasing. It must take several hundreds of years to go through an entire course. Besides this general movement in one direction, the needle shows other variations: it has a small daily vibration called the *diurnal variation*. From sunrise it begins its

westerly sweep, which continues till about five P.M.: it then retrogrades, and continues to move east until it has reached its mean position, where it settles through the night. This arises from the sun's action on the oxygen of the air (23, 24.)

29. If a bar or needle is made to balance itself level or evenly in an axis before being magnetised, it will not lie even, if placed in the magnetic meridian, after it has been rendered a magnet. It points downward, or is said to *dip*. This dip or *inclination* of the needle is so great in some places as to make it stand nearly upright. But the dip varies with the latitude. On the equator the needle is nearly level; in the regions about the north and south poles it approaches the upright position. In this country it inclines or dips about 70 degrees. It is evidently owing to the earth's magnetic poles being situated deep in the interior of the globe somewhere in the arctic and antarctic circles. Captain Ross came to a place in 70° 5′ north latitude and 263° 14′ east longitude, where the needle stood perfectly upright, showing that the north magnetic pole was directly under that spot, being thus at a considerable distance from the north pole of the earth. On the other hand, there are places in the tropics where the needle has no inclination; and every such place is said to be in the *magnetic equator*, which is formed by drawing a line through all the points where this perfect level occurs. The magnetic equator does not coincide with the earth's equator, but deviates to each side of it, and forms on the whole a very irregular line. The level of the needle is evidently produced by the equal and opposing actions of the north and south poles. North of the magnetic equator the dip is north, and south of the equator it is south.

30. There is the same constant fluctuation in the inclination as in the declination of the needle. The inclination has been gradually diminishing in London for the last century. It also has daily variations. The aurora borealis has always an effect upon the magnetic needle, both in its declination and its inclination. Earthquakes and volcanic eruptions are accompanied with magnetic disturbances, which sometimes cause a permanent alteration of the needle. There occur, besides, agitations, called magnetic storms, which sometimes affect a whole continent simultaneously, and produce large vibrations in all the magnetic instruments. From all these circumstances, it appears that the earth's magnetism is undergoing incessant fluctuations and changes, some gradual and steady, others sudden and momentary.

31. Besides the inclination and declination caused by the earth's magnetic polarity, the *intensity* of the action has

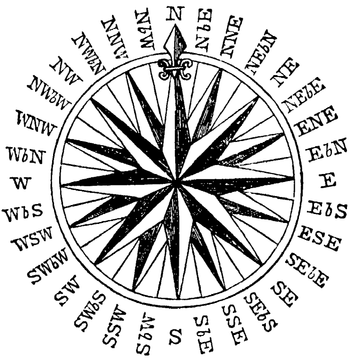
been made a matter of observation. This is measured by a separate instrument, and it is found to be least on the magnetic equator, and to increase gradually towards the magnetic poles; but like the other two elements, it is continually varying in the same place.

32. In regard to inducing magnetism upon iron, the earth acts like an ordinary magnet. A bar of iron, pointed to the pole like a dipping needle, and hammered, or cooled, or rusted in that position, becomes a magnet. So certain is this effect, that hardly any iron is ever found free from magnetism. The earth's inductive effect is rendered permanent in pieces of iron by the various modes of working and employing them, as well as by the spontaneous oxidation which occurs when they are lying unused. In high north latitudes, pokers and bars that usually stand on end inevitably acquire a small degree of magnetism. In the tropics, bars which lie on the ground nearly north and south are affected in a similar way.

33. The magnetic force, like all other influences spreading or radiating from a centre, diminishes as the square of the distance increases.

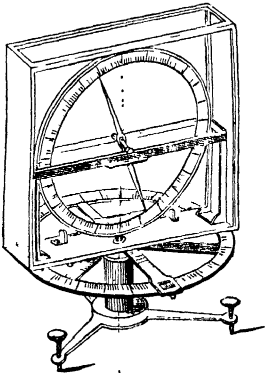
MAGNETIC INSTRUMENTS.

34. The apparatus designed to exhibit magnetic actions, not only serve for the study of the phenomena in a scientific point of view, but have also very important practical applications. The *mariner's compass*, which is a declination needle, serves to guide navigation in the open ocean, when there is no mark either in the sky or on the visible horizon to distinguish north, south, east, and west. By pointing always to the north, or within a known angle of the exact north point, it shows the course of the ship at every moment. The most essential part is a magnetised bar of steel, called the *needle*, which is supported horizontally on a central pivot, round which it is free to move and to point in any direction. The pivot rises from a circular *card* or dial, round the circumference



of which are marked thirty-two *points*. The preceding figure represents this card:—North, south, east, and west, are the main or cardinal points, and are indicated by their initial letters respectively, while the subordinate points are also marked by letters, as N*b*E for north-by-east, N N E north-north-east; and so on. To be able to recite the various points is said to "box the compass." The card and needle are fixed in a round *box*, enclosed by a sheet of glass, to secure it both from the agitation of the atmosphere, as well as to exclude dust, moisture, and other things which might interfere with the correctness of its indications. The whole is enclosed in another box, suspended by two concentric brass circles or *gimbals*, as they are technically called, and in such a manner, that the compass hangs, as it were, on points like a swivel, by which, during the pitching and rocking of the ship, the needle and its card remain in a horizontal position, and under all circumstances of motion indicate the various points correctly.

35. The *dipping* or *inclination needle* has to be suspended on an axis, with an upright graduated rim attached to it, to show the amount of the inclination. The instrument is represented complete in the figure.



36. A great improvement has been effected in the use of the compass by taking into account the action of the iron of a ship upon it, and providing a method of neutralising this action, whose effect would of itself render inaccurate the indication of the needle. A ship necessarily contains a large quantity of iron, which is sure to have some degree of magnetic power; and as the compass hangs in the stern, the attraction of the iron will always tend to make the needle turn to the direction of the ship's motion. It has been actually found that this source of disturbance is sufficient to cause very great mistakes as to the courses of vessels. The remedy for it was invented by Barlow, and is called *Barlow's Protecting Plate.* It is a plate of iron, fixed behind the compass, or between it and the stern of the ship, which of itself would produce a disturbance of the needle; but it may be so adjusted that its action shall be exactly equal to the action

of the other iron of the ship. Although this counteracting plate weighs only a few pounds, yet, by its nearness to the needle, it can be made as powerful as the whole mass of the ship's metal, whose average distance from the compass is necessarily considerable. The adjustment is made by finding out first the disturbance produced by the vessel on the compass; which is done by comparison with a compass placed out of the reach of the disturbing influence. The plate is then mounted in connection with the compass, and moved farther or nearer till it cause exactly the same amount of error, and the position thus found is made permanent. The ship's compass is taken on shore when this last operation is performed; and a complete neutrality can thus be effected.

THE MAGNETIC FLUIDS.

37. To account for the magnetic phenomena, it has been supposed that there are contained in the structure of iron and other magnetic substances two subtile fluids destitute of weight, colour, or sensible appearance, but imparting great energy to the solid matter. A portion of one fluid strongly repels another portion of the same fluid, but strongly attracts a portion of the other fluid. Each atom contains about it a certain quantity of both. In the unmagnetised state, the two neutralise each other, and have no influence of any kind; but by excitement, one fluid is driven towards one end of an atom, and the other accumulated at the other end. Being prevented, by the cause which rouses the excitement, from coming together upon the same atom, through their mutual attraction, they produce attractions between adjoining particles. The fluid accumulated at one end of one atom attracts the opposite fluid at the end of another atom; and as the fluids cannot quit their respective atoms, these are drawn together at their unlike ends. When two atoms are lying contiguous, if one has its fluids excited and polarised, the fluid accumulated at one end will draw the opposite fluid of the adjoining particle towards itself, and repel the fluid like to it (as the moon draws the water in the earth under herself), and the second atom will thus be polarised by the inductive power of the first. This second atom will have a like action on the third, and polarity will thus be propagated like waves. Each excited pole will cause an *opposite* excitement in the adjoining side of the next atom, and a *like* excitement in the far-off side.

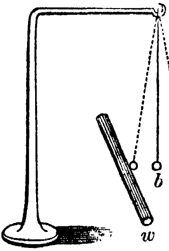
38. This hypothesis serves in some measure to represent or express the actions which are seen to occur; it cannot be said at all to explain them.

FRICTIONAL OR TENSION ELECTRICITY.

39. The electricity of Friction or Tension is the excitement that first received the name of electricity; and it is still called Common Electricity. It is usually developed by means of friction, although there are many other sources of it. Its most appropriate name is Tension Electricity—meaning that it possesses a high degree of tension, or tightness, or energy, so that when it is discharged, it strikes a sudden and powerful blow on whatever comes in its way. It agrees with magnetism in being a permanent and self-sustaining excitement; it is contrasted with magnetism in its being producible on almost all substances, and in its being very liable to be discharged or reduced to neutrality.

40. If we take a stick of sealing-wax, and rub it with a dry woollen cloth, we shall find that it has acquired the power of attracting light bodies, such as little bits of paper or fine dust. In its ordinary condition the wax has no such property; the attraction is caused solely by the excitement of the rubbing. A piece of amber (*electron*), or any resinous body, will show the same phenomenon. A glass rod, well dried and rubbed with a piece of silk, will in like manner become attractive for light bodies.

41. The entire range of this action is best seen by suspending a feather, or a pith-ball, by a silk thread, on a stand such as that in the figure. The lightness and mobility of the ball (*b*) make it a very delicate test of the existence of attraction. If, then, we bring the rubbed wax (*w*) near the ball, it will be attracted; but on the instant of touching, the attraction seems to cease; the ball drops away from the wax and flies off, and is now repelled by it; so that if we bring the wax near the ball, the latter moves still farther away. The contact brought about by the attraction at first has led to the communication of something to the ball, which causes it to be actively repelled by the wax. A rod of glass will exhibit the very same train of actions—first attraction, then contact, and lastly active repulsion.



42. If, now, we compare the effects of wax and glass on the same ball, a new distinction appears. Let the ball be acted on by the excited wax, or be attracted, touched, and finally re-

pelled. While in this state of *repulsion* by the wax, let an excited glass rod be brought near it—it is instantly *attracted* by the glass, brought into contact, and then repelled. If the wax be now brought near, the ball will be attracted once more; so that there is evidently an opposition in the characters of excited wax and excited glass; what the one repels, the other attracts, and what the one attracts, the other repels. They are like the opposite poles of a magnet. The friction thus developes a force which is polar in its nature. The discovery of the difference between wax and glass has led to the belief in two kinds of electricity—the one called *resinous*, from its being the excitement of wax and resinous bodies; the other *vitreous*, or the excitement of glass.

43. If we now take two pith-balls, and suspend them together or near one another, and apply the excited wax, we find both attracted, sticking for an instant on the wax, and then driven off, and both held at a distance by repulsion; but besides being repelled by the wax, we see that they are also repelled by one another. The very same happens with a glass rod, or any electrified substance; so that when two bodies have touched one and the same excited body, they acquire a mutual repulsion. It is now plain that the balls have received some influence by touching the wax, for after it is taken out of the way, they continue actively to repel one another. From this we infer that a body electrified by friction can communicate its excitement to another body by touching it; so that the excitement does not remain fixed in the place where it was produced, but can run along from one surface to another. This conveyance from place to place is called *conduction*. While the pith-ball lies on the surface of the wax, it receives a portion of the wax's excitement upon its own surface; and when two balls have each acquired excitement in this way, they show it by repelling each other, just as the wax itself repels one or both of them. It is manifest that the electricity that passes upon the pith-ball from the wax is of the same kind as the wax itself possesses. This can be still better proved by comparing, as follows, the wax with the opposite substance, or with the glass rod.

44. If the glass rod is used exactly as we have described in the case of the wax, the same thing will happen by means of it: the two balls will be both attracted, then both repelled, and when the rod is withdrawn they will remain repelling one another. But let us next act on one of the balls with the wax, and on the other with the glass, until the one ball is seen actively repelled by the former, and the other actively repelled by the latter. In this state let the balls be brought

within a little distance of each other; they instantly attract and fly together. Thus when both balls receive excitement from one substance, they repel, when they receive excitement from opposite substances, they attract, one another. The wax by touch gives its resinous excitement, and the glass a vitreous excitement; and the opposition of polarities thus created causes attraction, as in the magnet.

45. We have therefore the following general results arising from the rubbing of substances:—

1*st*, A great number of bodies, by being rubbed, acquire an electrical excitement, shown in attracting other bodies. Both the substances rubbed and the substances attracted may be as various as possible; showing that the property is not special and confined to one or a few substances, like magnetism, but universally diffused.

2*d*, This excitement can be communicated by touch to other bodies; showing that it does not remain attached to the excited particles, but may run along a surface and seize other particles, and give them the same power as if they had been themselves acted on by the rubbing. This property of *conduction* is not seen in magnetism.

3*d*, There are two opposite kinds of the excitement: exemplified, the one in wax, and all resinous bodies; the other in glass (vitreous).

4*th*, When two bodies receive the same excitement, they repel each other; when they receive opposite excitements, they attract each other. This is the law of magnetic excitement also.

46. It is found that the force of the attraction, or the repulsion caused by electricity, is inversely as the square of the distance; whence it resembles not only magnetism, but gravitation, heat, light, and sound.

47. It is necessary to state here the explanation given by Franklin of these phenomena, as it led to the adoption of the terms *positive* and *negative*, instead of vitreous and resinous, to express the two electricities. He imagined a fluid pervading all matter, strongly self-repulsive like a highly-elastic gas, and spreading itself as wide as it possibly can. This great repulsiveness is, however, modified by its second property, which is an energetic attraction or adhesion to all material bodies, so that each substance contains a quantity of fluid pervading it throughout, and firmly bound to each atom. In ordinary circumstances it is in a state of rest or equilibrium, or so counteracted by itself that it makes no motions of any kind; but when two bodies are rubbed together, the equilibrium is disturbed, one of the bodies acquires more than

its natural share, and the other less: the one contains, as it were, condensed fluid or ether; the other rarefied fluid. But this forced inequality cannot last: the condensed fluid tends to rush towards the rarefied portion, and in so doing, drags with it the substance it resides in, so that there is an attraction of the bodies themselves when their containing fluids are of unequal strength. Hence the tendency to come to an equilibrium, joined with the adhesion to the particles of bodies, brings on the attraction which we see. On the other hand, if two bodies have both an excess or a condensation of the fluid, their repulsion will be above average, and they will move away from one another.

48. This hypothetical assumption is not sufficient to explain all the phenomena; but it agrees with some of the most prominent of them, and brings out an additional fact, not apparent from any of the foregoing experiments, but completely established by other experiments, which we shall state as the fifth general law of electrical excitement.

5th, When a body is electrified by being rubbed, the rubbing body also receives an equal and opposite excitement. Thus the cloth that rubbed the wax is electrified as much as the wax, but with the opposite kind—that is, of the same kind as glass acquires. So the rubber of the glass rod is resinously electrified.

49. Now, according to Franklin, electrical excitement is the same as an excess or a defect of the electrical self-repulsive ether; and accordingly he calls the one excitement *plus* or *positive* electricity, the other *minus* or *negative* electricity. These terms are found to be so appropriate that they have been retained, and extended to all the *current* electricities to be afterwards described. The electricity produced on glass is what is chosen as positive; that on wax is therefore negative. It is therefore to be distinctly borne in mind that

Glass or vitreous electricity is *positive.*
Wax or resinous electricity is *negative.*

When a pith-ball touches sealing-wax, it is *negatively* electrified; when it touches glass, it is *positively* electrified. The cloth which rubs wax is positive; the cloth which rubs glass is negative. Positively electrified bodies repel each other; negatively electrified bodies also repel each other; a positive body and a negative attract each other.

CONDUCTORS AND INSULATORS.

50. Although the word *conduction* is used to express the travelling of electrical excitement from one surface to another,

the passage of electricity is very different from the passage of heat, also expressed by conduction. Heat is conveyed slowly from one portion of a mass to another, or from one body to another in contact with it; electricity passes quickly, and sometimes, we may say, instantaneously. Heat penetrates the interior, electricity travels on the surface. Electricity is not radiant like heat; it does indeed influence bodies which are at some distance, but the influence is quite of another kind from conduction, or from what passes by touch or contact.

51. But although conduction is a general property of the electrical excitement, it is very different for different bodies. On some surfaces the excitement runs from end to end with such quickness that no sensible time elapses; on others it travels slowly, so that a rod might be strongly excited at one end, and yet remain a long time neutral at the other end, such a body would be called a bad conductor. But the word *insulate* is used as the opposite of *conduct;* when a substance retains the electricity, and resists its passage from place to place, it is said to be an *insulator;* the electricity is cooped up there as in an *insula* or island.

52. The substances we have mentioned as convenient for producing electricity—namely, wax, resin, amber, glass, &c. —are all bad conductors, or insulators. The excitement on a stick of wax remains almost on the very spots which are rubbed; it does not pass along the surface except in a very small degree. The same is true of a glass rod, but not to the same extent; the glassy surface resists the passage sufficiently to be called a good insulator, but it does not resist so well as the wax. This property of insulating the electricity is essential to the success of such experiments as we have described with these substances: had the excitement run freely over the surface of the rods, it would have passed away by the hand, and disappeared as fast as it was produced, and the attractions would not have occurred. If the rods were wet, the effects would not be seen; for water in the smallest film is a good conductor, and would carry away the excitement, so that we would not know that any had been really produced.

53. The substances which form the best conductors are the metals. Although unequal in this respect, every one of them is a good conductor; so much so, that no perceptible electricity can remain on any surface, if there be a metal in contact with it and connected with the ground. The following table exhibits a series of bodies in the order of their conducting power: those at the top are the best conductors, those at the bottom the worst conductors, or the best insulators. Read from above downward, it exhibits the order of conducting power; from

below upward, it shows the order of insulating power; so that we can give it the one title at the top, and the other at the bottom:—

CONDUCTORS.

Metals.
Charcoal in its various forms.
Fused chlorides, iodides, and salts generally.
Strong acids.
Alkaline solutions.
Water.
Alcohol.
Damp air.
Vegetable bodies.

. . . .

Animal bodies.
Spermaceti.
Glass.
Sulphur.
Fixed oils.
Turpentine.
Resins.
Ice.
Diamond.
Shell-lac.
Oxalate of lime.
Dry gases.

INSULATORS.

54. It will thus be seen that *charcoal* stands next to the metals; but this holds only of its pure forms, such as plumbago and well-prepared wood charcoal. In coal there is a mixture of oily and pitchy matter, which lowers the conducting power, because these substances stand low in the table. *Fused salts* are good conductors, and next to them salts not fused. *Acid* and *alkaline solutions* are better than *water*. When *vegetable* and *animal bodies* are spoken of as inferior in conducting power to water and alcohol, it is to be understood that they are quite *dry*. Living vegetables and animals are always moist, which will give them almost the same conducting power as water. The best insulators are seen to be the *dry gases;* that is, gases free from steam and vapour. *Water* is a good conductor only in its liquid state; *ice* stands low; and *steam* is not a conductor, but it is so liable to deposit water or dew on the surfaces of bodies, that its presence is generally adverse to insulation. *Shell-lac* is very much used as the best practical insulator; it belongs to the class of resinous bodies, but excels all the others of its kind in this peculiarity. *Glass* stands much below the resins in insulating power, and it is surpassed by sulphur; but on account of its

hardness and strength, it has very frequently to be adopted as an insulator.

55. It is convenient to draw a line in the above table at the place where, for practical purposes, conduction ceases and insulation begins. This line is taken between vegetable and animal bodies: a dry vegetable substance, such as a piece of wood or a linen thread, is a conductor, though an imperfect one; a dry animal substance, as a silk thread, is reckoned an insulator, and used as such. The farther we go from these on either side, the respective peculiarities become more intense and decided. For good conduction, a wire of some metal, such as copper, is used; for good insulation, glass, or wax, or shell-lac, may be chosen. But the very best insulators are made conductors by being damp: hence dryness of surface must be carefully attended to. An electrical eel, brought to this country some time ago, was killed by a water-rat in spite of its electric discharges; which, though sufficient to stun very powerful animals, had no effect on the rat, whose fur is unwetable by water, and therefore, as a dry animal substance, proved a good insulator.

56. The substances presented in the table are merely a selection from the general mass of existing substances. Every body in nature is either a conductor or an insulator of electricity; but the foregoing list will suffice to show with what other properties a conducting or insulating power is usually combined. It is evident, for example, that the gaseous state tends strongly to insulation; that bodies abounding in combustible material, such as the resins, are insulating; that the presence of water always causes conduction; and so on. The character of a very wide range of substances is determined since the rank of metals and of vegetable and animal bodies is ascertained.

57. It was formerly considered that the insulators were the only bodies that electricity could be excited on; hence they were also called *electrics*, while the conductors, such as the metals, were called *non-electrics*. But this supposition is false. The metals are excitable by friction the same as the resins; but from their being good conductors, the electricity is apt to disappear from their surface as fast as it is formed. It is possible, by proper insulation, to make them electric, as well as sealing-wax or glass. In the electrical machine, the electricity is produced by the rubbing of a metallic surface on glass. The distinction of electrics and non-electrics, therefore, is no longer admitted.

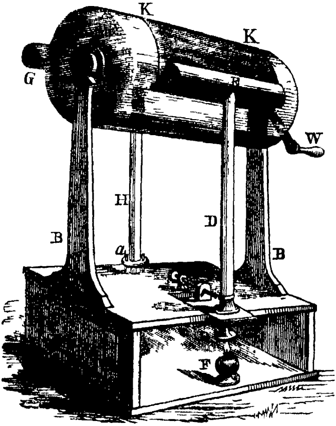
58. The earth is considered the general reservoir of electricity: whenever any excitement is connected with the ground

by a good conductor, it passes thither, and is lost by dissipation, like a wave spreading out on a boundless sea. The earth is generally neutral, or very slightly charged; and electricity of high tension will always run towards a body with either no charge, or with a feebler charge, and still more with an opposite charge. If the earth were negatively electrified, positive electricity would run towards it with still more energy than if it were neutral; whereas negative electricity would not run thither, unless its tension or strength were greater than the tension of the earth's charge. It is in all cases necessary to place insulators between an electrified body and the ground, in order to retain the charge.

59. When an electrified surface, or an electric charge of any kind, has two connections with the ground, or with neutral surfaces where it can spread, it always passes by the best conductor, even although this should be by far the longest path. Thus a metallic rod would be preferred to a line of water, water to dry wood, and wood to glass.

THE ELECTRICAL MACHINE.

60. In order to procure electricity in large quantities, and of great intensity, a rubbing machine is constructed, called the Electrical Machine. Its essential parts are *a cylinder of glass* mounted on an axle on which it may be turned, a *cushion* covered with a metallic paste, and a *metallic cylinder* to take the electricity off from the glass. The figure represents such a machine. A A is the glass cylinder revolving on an axis in the two supports B and B, which are either of wood or glass. E is a cylinder, carrying the cushion that rubs on the glass. This cushion is commonly separable from the cylinder, and when placed in it, rests on a spring, which keeps it close to the glass during the friction. The



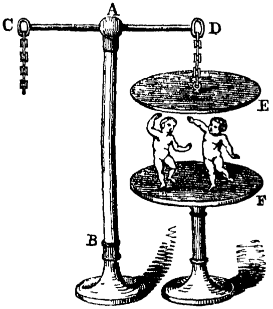
cylinder E has a metallic surface of brass or tin, and it is supported on a pillar D, which is an insulator made of glass. On the other side of the glass cylinder is the metallic cylinder G, destined to receive the electricity evolved on the former. It does not of itself rub on the glass, but it is armed with a row of brass points, which almost touch the excited cylinder, and which are specially adapted to carry off the electricity, and spread it over the metallic surface. This cylinder is called the Prime Conductor, or first receiver of the excitement, and it is supported by a glass pillar, H, in order to be insulated. As the electricity of glass is positive, this cylinder must always receive positive electricity; hence it is called the Positive Prime Conductor. Since the cushion cylinder gets itself charged with negative electricity, it is called the Negative Prime Conductor. The base of the pillar supporting the negative conductor is movable by a screw *s s*, to regulate the pressure of the cushion. A flap of silk (K K) is fastened to the upper edge of the cushion, and covers the upper half of the cylinder; this may both increase the friction given to the glass, and help to retain the electricity on the surface till it go round to the points on the prime receiver. The surface of the cylinder and of the insulating pillars must be kept warm and dry during the working of the machine; and for this purpose a permanent heating body is sometimes kept near, such as an iron heater or a lamp (F) applied to the hollow (D) of each glass pillar. Although the cushion cylinder is on an insulating stand, it is not generally insulated when the machine is worked; insulation is used merely for certain special experiments. Accordingly, it is usual to connect the negative cylinder with the ground by a chain. If it were not so connected, it would become highly charged with negative electricity, and resist the further disengagement of the excitement.

61. The operation, then, consists in turning the cylinder rapidly by the handle W. Its surface is rubbed hard on the metallic paste, which the cushion is smeared with, and electricity is evolved of both kinds. The positive excitement appears on the glass, and is carried round and taken off by the points of the prime conductor, and there accumulated, being cut off from all conducting communication with the ground. The negative excitement is given to the metallic coating of the cushion, and thence to the whole of the negative cylinder; but for the sake of getting additional excitement from the machine to the other side, this is carried to the earth by the chain.

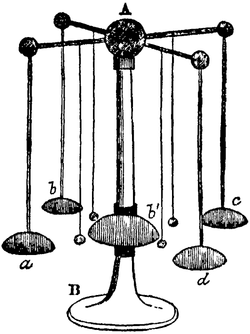
62. While the positive prime conductor is thus receiving a constant stream of positive excitement, we may derive from

it electricity for any experiments that we desire to make, or we may observe upon itself the various properties of electrical excitement. Such experiments as we detailed at the outset can now be made with far greater effect than with glass rods or sealing-wax; the attractions and repulsions will be much more powerful. Feathers, pith-balls, and the like, will be attracted and repelled with rapidity and vehemence. And by means of metallic rods, electricity can be conveyed to any surfaces we please at any distance.

63. A great number of striking and beautiful experiments can be made by electrifying bodies, and making them display the attractions and repulsions caused by the electricity. For example, in the figure, B is an insulating stand formed of a glass pillar, A is a brass knob at the top of the pillar, and through this nob runs the brass rod C D, which suspends by a metallic chain the metallic plate E. A second plate F lies a few inches beneath the first, and rests on a stand which is not insulated. A few light figures of pith or other substance are laid upon the lower plate, and the end of the rod C is brought into connection with the prime conductor of the machine, either by touching it, or communicating by a chain or rod, or by being so near, that the electricity can fly off to it in sparks. If the machine is now worked, and electricity conveyed off to C, it will run along C D, and down to the upper plate, and remain there, since it cannot go down by the glass pillar to the earth. The upper plate, in consequence of its charge, will attract the figures from the lower plate, and make them fly up to it; but as soon as they touch, they will become themselves electrified by conduction, and be repelled or thrown down from that plate; but they no sooner touch the lower plate, than they give away their excitement to it, whence the charge passes off to the ground, and they are neutral as before. The upper plate now attracts, and electrifies, and repels them again; and they move up and down a second time, and discharge their excitement to the lower conductor, and are ready to be attracted upwards a third time, and so on. In short, so long as the upper plate is electrified, they are kept dancing up and down; hence the name *Dancing Figures* is given to the apparatus.



64. The *Electrical Bells* is another apparatus for showing the same effect. The stand B carries upon it at a little height a bell *b′*, and above the bell a glass insulating rod terminating in the brass knob A. From A proceeds four brass rods, and from their extremities are suspended by brass rods or chains four bells *a*, *b*, *c*, *d*, hanging on a level with the ball *b′* on the pillar. Four brass balls are suspended by silk threads from the arms running out from A, so as to hang between the outer bells and the central one. Electricity is then conveyed to the central knob, or to any of the arms, and runs over the whole of the arms and the outer bells, but it is prevented by the glass pillar from passing to the middle bell, and by the silk threads from passing to the brass balls. The outer bells are therefore highly charged with the electricity of the positive prime conductor, and each attracts the ball next it. The balls move up, therefore, and strike the bells; but no sooner touch them, than they are repelled, and fly in the direction of the central ball; which, being neutral and uninsulated, takes off their electricity, and with it their repulsion from the outer bells; so that the instant they strike upon the neutral centre, they are again attracted to the electrified bells, and immediately repelled as before. Thus, by incessantly swinging between the two, they keep up a tinkling as long as the electricity continues.



65. Another set of experiments on the same principle is made by feathers, heads of hair, or like bodies. When these are electrified, the repulsion that bodies in the same state always manifest, causes the hair to bristle up, and spread itself out as far apart as possible.

66. It can be easily proved by the machine, that while the glass cylinder acquires positive electricity, the rubber becomes negative. For this purpose the cylinder containing the rubber is insulated by removing the chain usually attached to it, and the positive conductor is connected with the ground. In this state the conductor that has the rubber will be excited, and its excitement can be turned to the same account as the other in such experiments as the above. But to test its character, we may use a suspended pith-ball and a piece of sealing-wax, which we know when rubbed to be negative. Let the

sealing-wax attract the pith-ball, and electrify it with its own kind, so as to repel it. Let the ball now approach the electrified conductor, which ought to be feebly charged; and it will be repelled by it also, showing that the electricity of this conductor is the same as that of the wax, or negative. If the ball had been excited by touching a glass rod, it would have been attracted by the cushion conductor. Such experiments will not succeed if the conductor is powerfully charged, because in that case the trifling excitement given by a piece of wax is completely overwhelmed by the conductor's excitement, and the ball is acted on as if it were neutral. A piece of excited wax, or any resinous surface, serves on all occasions to test which of the two electricities is produced.

67. The metallic paste smeared upon the cushion (a hair-cushion covered with chamois leather) is what is called an *amalgam;* that is, a combination of mercury with other metals. If a bar of tin, lead, or zinc, or any metal, be dipped into a vessel of mercury, the mercury will partially dissolve it, like water with a salt. A solution in this way of any other metal in mercury gives an amalgam. The mixture used for the electrical rubber is one part of tin and two of zinc to six of mercury; but different proportions have been used by different experimenters. With the addition of so great a quantity of solid metal, the mercury loses its extreme fluidity, and becomes viscid and pasty, approaching to an incoherent soft powder. It is spread on the cushion with the blade of a knife, and requires to be renewed from time to time; for besides being dissipated by the action of the machine, it seems to undergo some chemical or other change that gradually takes away its power of exciting the electricity.

68. Another form of the electrical machine, more powerful than the one just described, is what is called the Plate Machine; that is, instead of a cylinder, a flat circular plate is used. The cushion must then be double, so as to hold the edge as between one's finger and thumb; and the other parts must correspond to the shape of the glass. Two rubbers and two sets of points are commonly applied to the plate's edge, dividing it, as it were, into four quarters. The objection to such machines is their liability to crack, by the heating that all machines must undergo to make them thoroughly dry before being wrought. But a cylinder machine can be much improved in power by attaching two rubbers to the cylinder, one above and the other below, and enclosing both sides of the cylinder with rows of points, and also by reducing the thickness of the prime conductor (which must have the shape of a spur whose arms contain the two rows of points) to about an

inch. Such a machine has been constructed by Mr Straton of Aberdeen; and it yields many times the quantity of electricity that would be given by a machine of equal size made in the ordinary form.

69. A machine of great power has been constructed, which receives the name of Armstrong's Hydro-Electric Machine. It was observed by Mr Armstrong, that a jet of steam rushing out from an iron boiler, made the boiler give off electric sparks, showing that it had been electrified by this action. Accordingly, iron cylinders have been formed like the boilers of steamboats, and mounted with tubes for the escape of the steam in the form of jets. The steam is raised to a pressure of two or three atmospheres before the tubes are opened. It is then allowed to rush out in a row of jets, and in doing so it communicates *negative* electricity in great quantity, and of a very intense kind, to the whole outer surface of the boiler, while it is itself positively electrified in an equal degree. The boiler being supported on glass pillars, in order to be insulated, becomes so intensely charged that, if not relieved, it darts off sparks to great distances. No rubbing machine can equal such an apparatus in power.

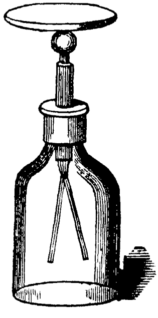
70. The mode of action in this machine has been thoroughly investigated and explained by Faraday. He has shown that the electricity arises from the friction of water globules against the edge of the steam-holes. When the steam rushes out at high pressure, it carries a shower of water particles with it, and these act as a rubber upon the metallic surface of the boiler; and the strong friction between water and iron is the source of the electricity. If the steam is dry—that is, if it is perfect steam, or the true elastic gas of water, and free from cloudy or watery particles—it produces no excitement whatever. If atmospheric air, or any other dry gas is used, there is no electricity excited; and it is completely proved that a gas can in no case serve as a rubber to evolve electricity. But if the gas carry with it a shower of particles either *solid* or *liquid*, the surface that it rushes through becomes electrified, and the solid or liquid particles acquire the opposite excitement. It depends upon the substance used what is the kind of electricity given to the metal. The iron boiler is made negative by the water particles in the steam current; but if we substitute for water oil of turpentine, olive oil, resin, or other similar bodies, the solid rubbed by them is positive and the jet negative. Either steam or dry air may be used to carry the powder, the gas having no action but to sustain the rubbing stream. The action ceases if the water-drops contain any trace of acid or salt, which would render them

much better conductors of electricity than drops of pure water. It is from its being too good a conductor, that a metal cannot be electrified by ordinary rubbing, like a piece of amber or wax. But the rapid rush of watery particles succeeds in charging even a metallic surface. If, however, the water is rendered too good a conductor, by an acid or a salt being dissolved in it, the difficulty of keeping the electricities apart is rendered so much greater.

ELECTROSCOPES AND ELECTROMETERS.

71. An instrument for *showing* the existence of electrical excitement is called an Electroscope; an instrument for not only proving it to exist, but also *measuring* its strength or tension, is called an Electrometer. There are many instruments of both kinds:—

72. A pair of pith-balls hung together serve to indicate the presence of electricity. If they are brought into contact with an excited surface, they become both charged with the same kind, and repel each other. Of course, if the surface touched is neutral, there will be no action.

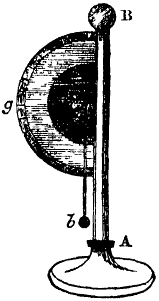


73. The Gold-Leaf Electroscope is on the same principle, but far more delicate. It is represented in the adjoining figure. A glass vessel has inserted in it a metallic rod terminating in two gold leaves, and surmounted by a metallic plate. The rod passing through the neck in the bottle is covered with shell-lac varnish, and surrounded besides by a glass tube. A very small degree of excitement communicated to the metallic plate will cause a divergence of the gold leaves. To ascertain the kind of the electricity, it can be compared with the influence of sealing-wax.

74. Both the pith-balls and the gold-leaves serve as electrometers to a certain extent; for in proportion to the strength of the charge will be the distance of the repelled balls or leaves. And if we estimate this distance by a graduated scale, we shall have a measure of the electrical tension. But there are many other arrangements for measuring the excitement, such as the following:—

75. The Quadrant Electrometer is represented on next page: A B is the stand, and *g* a semicircle of ivory, graduated according to the divisions of a circle. From the centre *c* hangs a strip of cane, with a pith-ball *b* at its other end. If,

now, the stand is connected with an electrical surface, so as to be itself electrified, the pith-ball hanging by it will share in the excitement, and be repelled, and rise up the scale. The degree to which it ascends will be a measure of the strength of the electricity.



76. Volta's Electrometer is analogous to the gold-leaf apparatus; but instead of gold leaves, it has two straws hung from hooks at the end of the metallic rod. A scale is fitted up in the glass vessel to measure the divergence of the straws. This instrument is much more delicate than the quadrant electrometer.

77. For measuring very strong charges, an apparatus of a larger kind is made use of. Such is what is called the Balance Electrometer, where the strength is measured by the weight which can be overcome by the repellent power of an electrical charge. One end of a rod balanced on the middle lies upon another rod, both ending in balls or knobs; when an electrical charge is communicated to the apparatus, the two balls repel each other, and the end of the balanced rod rises. The weight which can be lifted up by the rising end is a measure of the strength of the charge.

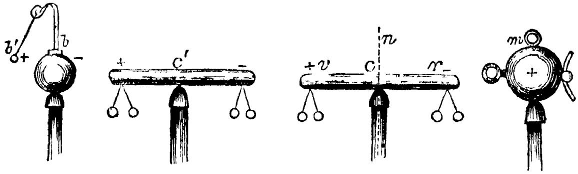
78. The Torsion Balance of Coulomb is a very important instrument, both in electricity and in other departments, for the delicate measurement of forces. A rod is suspended by a thread, so as to hang horizontally like the beam of a balance; and when this rod is acted on by any force, there is no resistance to overcome but its own inertia, and the twisting of the thread; the last is so very slight, that a large sweep of the rod takes place from a very faint action, and thus the minutest degrees of force can be measured and compared. Coulomb invented this instrument to investigate the law of electric force in relation to distance; and by it he proved that electricity resembled gravity and other central forces, and diminished as the square of the distance increased.

INDUCTION.

79. It has been seen that when electricity is evolved, both kinds are formed at the same time. The one of the two rubbed bodies has a positive charge, the other an equally strong negative charge. The same principle extends farther; we find that a charge cannot even exist on a surface unless there be on some adjoining surface an equal and opposite charge. Posi-

tive electricity cannot be insulated, and made to remain by itself; it will not pass into any situation where it cannot be accompanied with a counter charge of negative excitement. The polar character is rigorously sustained in frictional electricity, as well as in magnetism; we can no more have one kind of excitement alone by itself, than we can have a magnet all north or all south.

80. When a surface charged with electricity of one kind is in the neighbourhood of other surfaces, but not touching them, it communicates to them the *opposite* electricity. The apparatus best adapted for demonstrating this is a set of brass cylinders rounded at the ends, and placed on insulating stands.



Thus let *m* be the prime conductor of a machine; *c* and *c'*, two insulated cylinders laid end to end at a little distance from each other and from the conductor; and *b* a brass ball, with a pith-ball *b'* suspended to it. When the machine is wrought, the whole of the surface of *m* has positive electricity. Now the action of *m* upon the adjoining cylinder is such, that the nearest end *r* is electrified negatively, and the remote end *v* electrified positively. The cylinder has received no electricity by conduction; it has become polarised by induction, exactly as happens in magnetism. The middle *n* is neutral, and the two ends are charged with equal and opposite excitements. But this cylinder exerts its action on the second cylinder in the same way; the end of which next *v* is negatively charged, and the other end positively charged. The ball *b* also is affected by the positive end of the second cylinder, and made negative at one side and positive at the other, where it repels the pith-ball. Thus the prime conductor, without parting with any of its excitement by *conduction*, polarises a series of bodies by its *inductive* power. There is no limit to the number of bodies that might thus act on each other, except the tension of the conductor; but the action on each successive surface becomes gradually feebler.

81. If the remote end of one of the cylinders is connected by a conductor with the earth, the charge on that end passes off to the earth, and the opposite electricity spreads over the

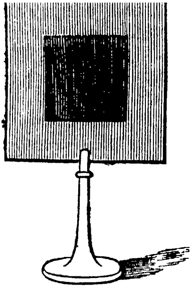
whole surface of the cylinder. Thus if the positive excitement of *v*, the far end of the first cylinder, were conducted away, the cylinder would possess all over a negative charge, as if it had been connected with the negative prime conductor of the machine. But if, on the other hand, without conducting off any portion of the induced electricity from any of the surfaces, we withdraw the prime conductor *m*, whose tension caused the succession of polarities, they all instantly return to their original neutral condition. The presence of the primitive source is necessary to sustain the action; and when this fails or is cut off, it is like the removal of a magnet from a soft iron bar—the temporary excitement ceases.

82. We may now understand why an electrified surface attracts a neutral or unelectrified body, such as a pith-ball. It is not that electricity causes attractions between excited and unexcited bodies, the same as between bodies oppositely excited; but that the pith-ball is first rendered opposite by induction, and attracted in consequence of this opposition. A pith-ball at a few inches' distance from an electrified surface, is charged with electricity by induction; and the kind being contrary to the kind of the surface, attraction ensues; when the two touch, they become of the same kind by conduction. The case of attraction by excited surfaces is the same as the magnet's attraction for iron; an opposite excitement is first communicated to the body, and it is then attracted. If a series of cylinders were electrified as above shown, they would all tend to attract each other by their opposite poles.

83. It is a fact only lately discovered, that neither the prime conductor of the machine, nor any surface whatever, can receive or contain electricity, unless there be other surfaces near to contain an opposite charge of the induced kind. Whatever bodies are in the neighbourhood, the walls and furniture of a room, &c. are made use of for this purpose, as well as anything that is casually brought near. If the surrounding surfaces are easily excited, and can take on the induced electricity well, the prime conductor of the machine, or any connected surface, may acquire a high charge; but if these surfaces are difficult to excite, if they are of the non-conducting kind, the prime conductor will receive only a feeble charge. The second pole is in this case not readily observable—it has a sort of irregular character; but decisive experiments were made by Faraday, which proved that where there is not a confronting surface for the induced charge, it is impossible by the most powerful machine to put the least possible excitement on any surface whatever. It had previously been shown, that if the outer surface of a hollow

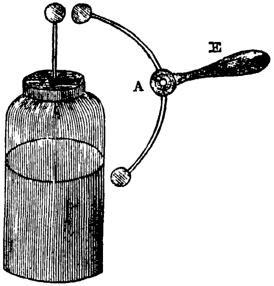
sphere were charged, no electricity would pass to the inside, although there were a free communication by holes; and Faraday put the thing to the test on a large scale by constructing an insulated room, which he went into with his electroscopes, while the outside was charged by a large machine; whereupon it was found that no trace of excitement appeared in the inside. The reason is, that there is not room in the interior of a continuous hollow surface for both excitements to exist apart, and yet confront one another.

84. There is a limit placed to the accumulation of electric excitement on any surface. But the better the opposition surface given for the induced electricity, the higher the charge that it is possible to communicate. Accordingly an apparatus was devised last century by a Dutchman of Leyden, thence called the *Leyden jar*, which completely suits the polar nature of the charge by providing two equal surfaces, held apart by an insulating medium, to receive both the primary and the induced electricity. The simplest form of this double-surface apparatus is a pane of glass, with a coating of tinfoil on each side, the coatings being equal to one another, and smaller than the glass, so as to leave an uncoated margin all round, as represented in the figure. If one of the coatings is connected with the machine, and positively charged, it will act by induction through the glass upon the other coating, and excite it in the manner already described in the case of the row of brass cylinders. The near or inner surface of the second coating will be made negative, and the other surface positive; and if the coatings are insulated, this state will continue. But if the outer side of the second coating is connected with the ground, and the positive induced charge taken off, the surface will have only a negative charge left corresponding to the positive charge of the first coating, directly derived from the machine. We have thus a true polar charge, a positive and a negative surface separated by an insulating medium. The excitement is now no longer *free*, but *fixed;* neither of the electricities will run off by touching the coating with a conductor; they are, as it were, held locked in one another, and the apparatus is almost like an unexcited body. There will be no attraction of pith-balls, because the electricity does not need surrounding surfaces to act upon by induction in order to maintain itself. A



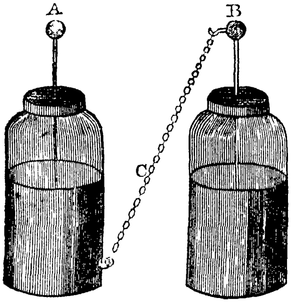
very high charge can now be administered, if we keep the outer surface of the second coating connected with the ground, while the first is connected with the machine. There being a proper surface for the induced excitement, the primary excitement can rise higher and higher; but it will not show its strength in the same way as on a single surface. The dead lock of the two prevents them from acting singly; and we hardly know of the accumulation that has arisen, till the two surfaces are connected by a conductor, such as a metallic wire; we then see a bright spark, and hear a sharp snap, as if a violent shock had been sent through the apparatus.

85. The Leyden jar is a glass bottle with two coatings of tinfoil, one outside and the other inside. The coatings do not reach to the mouth of the bottle, so that they leave a rim of naked glass. A plug is fitted tightly into the mouth, and covered with varnish, and through the middle of it a brass rod is passed, with a chain hanging to its lower end, to make a connection with the inner coating. The upper end of the rod is formed into a round knob. The figure represents the jar with the apparatus used for discharging it; which last is a glass rod E to hold in the hand, and two brass arms connected at A by a movable joint. Through these two arms the two electricities run to meet one another, when one end touches the outside of the jar, and the other comes near the knob connected with the inside. In using the jar it may be held in the hand, and the knob presented to the prime conductor of the machine; the inside thus acquires a positive charge, and induces a negative one on the near surface of the *outer coating* fronting it; that is, on the inside surface. The outside surface of the outer coating would then be positive; but it being in the hand, the positive electricity passes away, and leaves the outer coating entirely free for a negative charge, which it thus possesses, and thereby fixes the positive charge in the inside. The transmission of more electricity from the machine to the inner coating, induces more on the outer, till the jar is as highly charged as the strength of the excitement communicated can make it. If, now, we try the outside with a pith-ball or other electrometer, we find no sign of electricity; if we try the inside through the projecting rod, we find indeed a very feeble charge; but there is no appearance corresponding



to the actual excitement held by the two coatings. Let us next apply the discharging rod; and having touched the outside with one ball, let us approach the knob with the other; and while these are yet an inch or two inches apart, the two electricities will flash together with the usual spark and noise. The tension or strength of the excitement is shown by the distance that may thus be broken through by the attraction of the opposite states for one another; just as the strength of the excitement of the prime conductor of the machine is judged of by the distance that sparks will pass through to a conductor placed near.

86. The electricity driven off from the outer side of the outer coating by the induction, instead of being conveyed to the earth, may be passed to a second jar, and may communicate to it a charge by the same process as the first jar is charged. Thus, in the figure, let A, the knob of the first jar, be in contact with the prime conductor of the machine, and let the outer coating be insulated, by resting the jar on a plate of glass or other insulating substance. A chain C passes from this outer coating to B the projecting rod of the second jar, whose outside communicates freely with the ground. By working the machine, the inside of the first receives a positive charge, which excites a negative state in the outer coating, and in consequence drives off positive electricity by the chain C to B, and thence to the inner coating of the second jar. A second induction now takes place; and in order to render negative the outer coating of this jar, positive electricity must be driven off to the ground. Thus both jars are charged, and in the same way a succession of jars might be charged; but the second is weaker than the first, and the third than the second, and so on, until at last the excitement would be imperceptible. After being charged, the jars may be disconnected, and each discharged by itself. It happens in this case, as with the cylinders, that one polarity is but the commencement of an endless series of polarities which can be traced to a certain distance, growing weaker and weaker at every step.

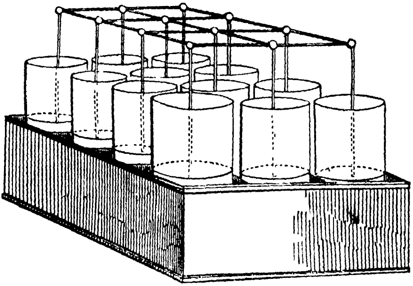


87. The strength of charge which can be communicated to

a Leyden jar depends upon the thinness of the intervening glass. The whole *quantity* of the excitement will of course be greater as the jar is larger in size; but its tension, strength, or intensity increases as the thickness of the glass is reduced. The glass offers a certain resistance to the induction, and a certain degree of tension is expended in overcoming this intermediate resistance. The particles of glass are themselves successively polarised, and it is only the surplus of the inductive power that reaches the other coating. Hence the charge on the second coating is never equal to the charge on the first; and consequently the reaction of the second does not suffice to fix the whole of the excitement of the other. This is the reason why a certain amount of free electricity may be detected in the coating that was connected with the machine. If, however, this free electricity is taken off, the remaining quantity will become insufficient to support and fix the whole of the induced charge in the other coating, and a small portion of its electricity will now be rendered free, and become sensible to an electrometer. Should this also be conducted off, the inner side will next show a surplus; and by touching the two sides alternately, the whole charge may at last be taken off, from this constant necessity for there being a surplus on one side to fix the entire charge of the other. The thickness of the glass gives rise, besides, to what is called the *residual* charge; for after discharging a jar, if we apply the rod again, a second discharge of a feeble kind will be observed. The first discharge neutralised the electricities of the metallic coatings; they being good conductors, their portion ran off first, and came together before the excitement of the glass had time to go off; and this remaining excitement furnishes the second discharge. There must be a limit to the thinness of the glass of the jar; for the electricity in polarising its particles evidently tends to tear them out of their natural cohesive position, and to join them together by new sides, corresponding to their electric poles. When the strength of the excitement comes up to a certain point, it forces its way through by making a hole in the glass. Jars are often pierced in this way and rendered useless by the violence of the polar coercion of their particles overcoming their cohesion.

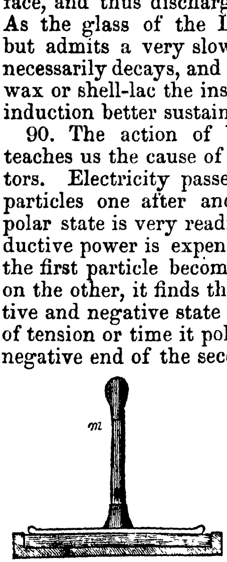
88. In order to accumulate electricity in great quantity, a series of jars are joined together, forming a *Leyden battery.* All the insides are connected by joining their projecting knobs together, and the outsides are connected by passing wires round them from one to another, or resting them all in a continuous metallic bottom. The principle of the charge is the very same as for a single jar; and the effect is nearly what

would follow from one enormous jar whose extent of coatings is equal to the sum of those which constitute the battery.



89. The insulating substance which separates two conducting surfaces, and enables them to sustain opposite states, is called by Faraday a *Dielectric.* All insulators are dielectrics, and the best insulators are the best dielectrics; for in as far as the dielectric is a conductor, it allows electricity to pass through in its own kind to the opposite surface, and thus discharges instead of charging the apparatus. As the glass of the Leyden jar is not a perfect insulator, but admits a very slow conduction of electricity, the charge necessarily decays, and becomes at last extinct. With sealing-wax or shell-lac the insulation would be more perfect, and the induction better sustained.

90. The action of bodies in the capacity of dielectrics teaches us the cause of their being insulators or non-conductors. Electricity passes through bodies by polarising their particles one after another; but in a good conductor the polar state is very readily induced, and exceedingly little inductive power is expended in bringing it on. Thus suppose the first particle becomes positive on one side, and negative on the other, it finds the second so easy to induce into a positive and negative state in its two sides, that without any loss of tension or time it polarises it; and in the same manner the negative end of the second renders positive the adjoining end of the third and the further end negative. Conduction is supposed to be nothing but a series of inductions; but these in some bodies are easily effected, in others with difficulty.



91. The *Electrophorus* is a very useful piece of electrical apparatus, depending upon induction. It consists of a plate of metal, covered, but not to the edge, with a plate of resin, which is poured on it and spread out in the melted state. On the cake of resin is

placed a second metallic plate having an insulated handle (*m*). If the resin be excited by rubbing, it will have a negative surface; and by laying on the cover, it will be electrified by the contact; the lower surface lying on the resin will be positive by induction, and the upper surface negative. If we touch the latter with a conductor, such as the finger, its negative charge will be taken off, and positive excitement diffused over the whole. By this apparatus a small positive charge can be easily obtained at any time.

92. The *Condenser* of Volta is an instrument intended to accumulate electricity, when of a very feeble strength, such as what arises in chemical actions. It is analogous to the Leyden jar, or rather to the coated pane of glass. It consists of two metallic plates placed on one another, with a very thin layer of gum-lac varnish between them. The thinness of the gum-lac, which serves as the dielectric, allows the induction to pass through, even although the excitement be very feeble; and therefore there can be an accumulation of weak electricity in the same way as the Leyden jar accumulates intense electricity. The condenser serves as an electrometer and electroscope, to attest the presence of excitement when too faint to show itself without accumulation.

93. When a single surface, such as the prime conductor of a machine, is charged by the help of the surrounding surfaces which serve to sustain its inductive charge, the intervening air is the dielectric; but this dielectric is easily overcome or ruptured, so that a discharge can take place through it at great distances. Thus if we hold our knuckle within an inch or two of the conductor, when the machine is at work, the hand serves as one of the random surfaces for the conductor to exert its induction upon, and becomes strongly negative, and the whole intervening air is polarised like the glass of the Leyden jar; but the air very soon gives way, and allows the opposite excitements to flash together in a spark. The more rarefied the air, the greater the distance that sparks will go through from one surface to another.

94. In the case of an excited single surface, it is found that unless it be a ball, the excitement is not equal on all parts of the surface. The prime conductor is generally a cylinder rounded at the ends into hemispheres, and the electricity is always stronger on the ends than on the body of the cylinder. If we take a large globe and a small one, and join them together by a rod, and pass electricity upon them, the charge will be most intense in the smallest. If the one have four times the surface of the other, the excitement of the large one will have only one-fourth of the strength of the excitement in the

small. Whenever a surface approaches to a point or an edge, the intensity proportionally increases. The cause of this unequal distribution is found in the theory of induction:—

. We have seen that without a confronting surface to sustain an opposite charge, no body can possibly receive excitement; and the better provided a body is with a surrounding surface, the greater the charge that it can take on. Now, if we have two unequal balls in the same rod, their excitement depends upon the induction which they can exert on the surfaces about them; but the small ball being in the same room as the large, it has as good and extensive an inductive surface presented to it as the other. The two have unequal surfaces of their own; but they have the same confronting exterior surface in the walls and furniture of the room, and on this unequal proportion of surfaces depends their unequal capacity of being excited. If we had twelve balls of different sizes, all strung on one rod, and hung in the middle of a room, they would take on exactly equal charges; but if we had one ball in one room, and another in a different room of other dimensions and material, the charges would probably be unequal—the ball that found most facility in polarising the surfaces around it would take on the highest excitement. Now the rounded end of a cylinder is acted on like a small ball; for a larger surface is confronted with it than with an equal portion of the body of the cylinder. Suppose that, in the latter, four square inches had such a degree of curvature as to be opposed to one-tenth of the whole surface of the room, and that four square inches on the end made a hemisphere and confronted half the room (as the surface of a whole sphere would confront it all round), then the intensity on the end would be five times that on the middle. Accidental arrangements will make one part of a surface more intense than other portions equally well curved and exposed to surrounding surfaces; a metallic plate, for example, lying near one end of the prime conductor, will cause that end to bear a higher charge. A prime conductor of a machine working in a tinsmith's shop, would rise up to much more intensity than in an ordinary sitting-room. If a metallic cylinder were enclosed in a larger cylinder, it might be charged to a considerable degree; for this would be to make a perfect Leyden jar instead of the very imperfect way that the second surface is furnished by the walls and furniture of a room. The obstacle to the charge in this case would be the weakness of the dielectric; we would find it necessary to make the outer cylinder considerably larger than the inner, to allow some thickness to the intervening air, otherwise the electricity would break through and discharge itself.

95. We may now understand the cause of the very great intensity of the excitement at points and edges, and the tendency that the electricity has to pass off from them. A point is a very small surface, confronted with a very large exterior, and the extent of the induced surface allows a very high intensity to be attained. This intensity favours the discharge by increasing the action upon the dielectric of air, so that the electricity will pass off from a point to an opposite body at a much greater distance than it would pass through coming from the round bulge of a large blunt cylinder. Hence if a surface is armed with points, these will rob it of its excitement, and probably disperse it by their discharging force. A row of points are used, as we have seen, to take up the electricity from the cylinder of the machine; they being as powerful to receive excitement from a surface where it is in excess, as to pass it off to a surface where it is deficient. Of all single surfaces, a flat plate will take on the least intensity, and a sharp point the greatest. It is therefore necessary that surfaces which are intended to retain electricity should be well rounded, blunt, and smooth. And on the same principle it is requisite to keep the electrical apparatus free from particles of dust, which, like points, take on an intense charge, and fly away with a large share of the excitement.

THE DISCHARGE.

96. The Leyden jar is discharged by establishing a conducting communication between the two surfaces. But though this is essentially the manner of the discharge in all cases, it is usual to reckon three varieties of circumstances wherein it may happen, making, as it were, three different modes of annulling the excitement. These are called, 1*st*, The *conductive*, 2*d*, The *convective*, and 3*d*, The *disruptive* discharges.

1*st*, The *conductive discharge* is exemplified in the slow discharge of a Leyden jar through the glass, which, not being a perfect dielectric, allows of conduction to a small degree. Also when the air between an excited single surface and the surrounding surfaces is damp, the line of watery particles causes a slow communication by conduction, which gradually discharges the excitement. Again, if the uncoated glass of the Leyden jar is damp, a gradual discharge of the same kind takes place.

2*d*, The *convective discharge* is exemplified when pith-balls are attracted and repelled by a conductor, and then by touching some distant body lose their charge and become attracted again, as in the electrical bells and dancing figures. In this case the ball acquires by contact a certain amount of charge, which it carries off and communicates to the opposite induced surface, serving as a go-between to carry positive electricity to the negative surface, and negative electricity to the positive, and bringing about in this way a neutrality or equilibrium. Particles of dust tend to discharge surfaces by this process. In like manner particles of air are set in motion, and convey the electricity from one surface to its opposite. The intense action of points generally causes a current of charged air to run out from them, whose place is supplied by other air that acquires a charge in its turn, and is repelled like the previous portions. There is always a repulsion created by the passage of electricity from points, which can be made use of to create a rotatory motion, by making a sort of wheel with wire spokes, ending in points all bent inwards in one direction, and the whole revolving on an axis. The action is not unlike the force in Barker's mill. (See HYDRAULICS.)

3*d*, The *disruptive discharge* is the breaking or forcing of the dielectric, as when the glass of the Leyden jar is broken through. This arises when the twist given to the particles by their electrical state is stronger than their mutual cohesion. Glass is generally able to resist such a power, but the air offers very little resistance; hence disruptive discharges readily occur in it. This discharge may be exemplified by placing a card between one of the balls of the discharging rod and the coating of a Leyden jar, and passing the electricity through the card; the opening which it forces can then be seen, and from it we may form some idea of the action that has taken place. The hole is very small, such as would be made by a fine needle; but it is widened on both sides, as if the force had come equally upon it from each coating. Whenever any bad conductor, such as a piece of wood, is put in the way of a discharge, it is split up or pierced in the same manner, if the charge is sufficiently powerful.

97. The disruptive discharge is always accompanied with a flash of light. This has various shapes, according to the conductors used. Between two good conductors of rounded or blunt surfaces—such as the ball of the discharging rod, and the side of the jar or its nob—we have the *spark*, which is a round ball or globule of light, which passes somewhat zig-zag from one to the other. This corresponds also with the most concentrated and energetic form of the discharge. The distance over which the spark will go, disruptively through the

air, depends upon the force of the charge, and the goodness of the conducting surfaces between which it runs. From a point, or between a good and a bad conductor, the electricity, passing off, produces a *brush* of light spreading out from a centre. The convective discharge through the air yields in the dark a *glow*. When the air is rarefied, the discharge is made easier, and will pass over a greater distance. In an exhausted receiver it will pass through two or three feet in a lambent aurora flame. In the perfect vacuum light is seen, showing that empty space may take on an illumination. "The spark is very bright in condensed atmospheric air, white and intense in carbonic acid gas, red and faint in hydrogen, yellow in steam, and of an apple-green colour in ether and alcohol." By laying on a glass plate stripes of tinfoil or gold leaf, cut across and separated at every inch or short interval, and passing electricity through the whole, there will be a disruptive discharge, and a spark at every break of the continuity, and the entire metallic line on the plate will be illuminated. A great many striking effects of a similar kind can be produced in the dark from the electric light.

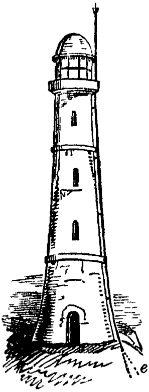
98. The concussion given to the air by the shock makes the sound that we hear, which is like the sharp crack of a whip. Both the intermediate air and the surfaces discharged are severely agitated by the sudden return from their electrified to their natural state.

99. There is a very perceptible sulphurous smell accompanying the discharge of electricity. The cause of it has been traced by Professor Schönbein to a peculiar substance formed during the discharge, to which he has given the name of *ozone;* and he has shown that the same substance is produced in other ways, and has certain remarkable properties, such as the power of bleaching cotton, like chlorine.

100. Electrical discharges have an acidifying tendency—that is, they form acids when the requisite ingredients are present. Thus nitric acid is sometimes produced in the air by the agency of atmospheric electricity; and alcoholic liquors are turned sour, or made to pass into the acetous or vinegar fermentation.

101. When the discharge is interrupted by an imperfect or inadequate conductor, it tears, splits, heats, and sometimes sets fire to bodies. Very thin wires are melted; combustible substances, such as phosphorus or gunpowder, are inflamed. The human body feels a violent stunning blow when a charge is sent through it; a very strong charge may cause irrecoverable blindness, or even instant death. A Leyden battery of twelve jars could receive a charge sufficient to kill a man;

produce its destructive effects. When a house has a metallic roofing, or whether it has or not, strips of lead should be built into the walls, and connected with one another, and with all the metallic masses of the house, so that wherever lightning strikes, it may find a metallic conductor near to convey it harmless to the ground. The rod ought not to terminate in a dry conducting body, but be conveyed if possible to moist earth (*e*), or to a well, so that the electricity may be at once discharged into a good conducting medium.



107. For the protection of ships, a continuous metallic line is necessary from the mast-heads to the sea. But the conductors in this case must be suited to the changes that have to be made in the masts and rigging during the vicissitudes of a voyage; hence they are made into a chain, or formed of thin flexible strips of copper.

108. If a thunder-storm strike on a house that has no metallic protection, it will choose in preference bell-wires, damp walls, or gilded pictures; a human being will be preferred to dry walls or floors; hence the danger of such a visitation. But the wooden floors are better conductors than woollen cloth or feathers; hence people lying in bed in the middle of a room are likely to escape. The greatest risk is incurred when a good conductor is afforded so far, and then cut short, and an insulating substance succeeds: the lightning is thus attracted and conveyed a certain way with ease, but has then to force its passage by violence, or by going out of its course, to meet in with some tolerable conductor. The human body, from its moist state, stands high in the list of conducting substances, and would be preferred to a great many other things.

109. It is dangerous to stand under trees in thunder-storms. A tree is a slightly better conductor than a human body, and would receive the discharge in preference; but the very fact of its attracting the lightning, while it is not a sufficiently good conductor to carry it quietly to the earth, is a reason for not standing near it. The tree itself may be shivered to pieces, and a portion of the shock besides communicated to other objects. In a forest, where there is a large mass of intervening matter, living beings may pass unharmed.

110. For making observations in atmospheric electricity, a conducting rod is used; but it has to be very carefully insulated, so that it may receive all its excitement from the air,

and neither give to the earth nor receive any from it. In the Electrical Observatory at Kew, kept under the charge of the British Association, the principal conducting rod is a conical tube of thin copper sixteen feet high, and projecting from the cupola of the building. It rests below, within the cupola, on a very strong hollow glass pillar, which is the means of insulating it; and the insulation is very much increased by a lamp, which heats the inside of the glass, in the manner already shown in the electrical machine. There is a certain temperature which renders glass almost a perfect insulator; and although this temperature cannot be given to the whole of the pillar, yet if the lower end is heated higher and the upper end lower, there will be some intermediate portion which will have the exact degree for insulation; and this portion will resist the passage of the electricity as well as if the same degree were maintained through the whole length. A pair of fine platinum wires are soldered to the upper end of the conducting rod; and to increase still farther its attraction for the electricity of the air, a lamp is also suspended at the top, and kept burning. It is found that flame has the power of rapidly receiving or dispersing electricity. The apparatus for lowering and raising the lamp is a silk cord running up the hollow of the rod, and attached to it alone. The lower end of the rod branches out into four brass arms in connection with electrometers, which constantly exhibit the strength of its charge, and show whether it is positive or negative.

111. The aurora borealis has been supposed to be a case of faint lightning discharged far in the upper air, where the rarity is so great that it may flash over great spaces, as we see in an exhausted receiver. But the coincidence between the aurora and distractions of the magnetic needle, render it likely that it is some manifestation of magnetic, rather than thunder and lightning, storms; which is confirmed by the north and south direction of the streamers. This, however, and indeed the whole subject of atmospheric electricity, is as yet very imperfectly understood.

SOURCES OF ELECTRICITY.

112. Hitherto we have regarded friction as the source of electrical excitement; but there are many other ways of evolving it. In general, all disturbances of the molecular state of bodies, whether mechanical or chemical, are liable to produce electricity. All the sources of heat (as well as heat itself), are sources of electricity. We shall now enumerate the various sources in detail :—

1*st*, *Cleavage* and breakage of bodies is a source of electricity. If a plate of mica is rapidly cleaved in the dark, there is perceived a feeble phosphorescent flame, and we find that the two faces have become charged with opposite electricities. From this it appears that crystals have a permanent polarity in their particles, which is converted into free electricity when they are separated. In the same way, if we break a roll of sulphur, or pound it to pieces, it will be seen to be electric.

113. When two substances have been adhering together by a firm cohesion, if they are suddenly broken asunder they show electricity on the separated faces. If we pour melted sulphur into a wine glass, and, while soft, stick into it a glass tube to be a handle to the mass, and leave it to cool and harden, it will have contracted an adhesion for the glass. If it is now abruptly drawn out, so as to break this adhesion, it will be seen that the two surfaces are electrified.

2*d*, *Pressure.*—If we take the plates of mica, or other crystal formed by cleavage, and press them together, and suddenly withdraw them, we find they have acquired electricity. But the effects of pressure, as of friction, are greatest with unlike surfaces. Let a disk of wood be covered with silk, and the silk coated with resin, and take a disk of metal, and press the two quickly together without friction; the surfaces, on being separated, will be excited; the metallic disk will be negative, the resined silk will have taken a positive excitement, contrary to the character of resinous bodies under friction. It was observed by Haüy that a crystal of Iceland spar, and a few other minerals, became electric by pressing it with the fingers: but the property is shown to be perfectly general; both good and bad conductors give signs of electricity under pressure. In making the experiments, the substances used are cut into very thin circular slices, and each is laid upon a disk with an insulating handle; they are then pressed together by holding a handle in each hand. A disk of cork, for example, pressed against another of caoutchouc, causes the first to have positive, the latter negative electricity. Crystallised minerals of a transparent character, such as sulphate of lime, are positive when pressed by cork. Slices of fruit, such as an orange, are negative to cork. If one of the substances pressed is a good conductor—a metal, for example—and the other an elastic substance, as a slice of pith, no effect will be produced; the electricity evolved is combined or discharged before the two surfaces can be separated. That this discharge is the cause of the nullity of effect, can be seen by making the separation slowly in the case of cork and orange;

for when the charge of the two surfaces is tested by the torsion electrometer, it is found much feebler than when the operation is quickly performed.

114. The two surfaces must have a difference of character of some kind or other in order to become excited by pressure. If we take a well-dried cork, and cut it across the middle, and press the two pieces together by the insulating apparatus, we may in some instances find an entire absence of excitement. But if one is heated, or receives a higher temperature than the other, a charge will be communicated when they are pressed together; the colder being positive, and the warmer negative. If the one surface be rough, and the other smooth, this difference will suffice to develop electricity, although both should be of the same material and of the same temperature; in this case the smooth surface will be positive, like the cold surface, and the rough surface negative.

3*d*, *Friction.*—This is the source commonly used in the electrical experiments. But in these we confine ourselves to the friction of a very few substances; as the rubbing of sealing-wax and glass rods with cloth, and the action of the glass cylinder of the machine upon a mercurial solution of zinc and tin. In order to investigate and explain the cause of the excitement of electricity by friction, it is necessary to go over a wide range of materials, and determine the precise effects of each pair when rubbed together. It is found that, except where the two faces rubbed are perfectly identical in character, electricity is always evolved by friction. In good conductors, it is necessary to insulate well the pieces rubbed, to keep the excitement from being carried off and lost. With this precaution, all the metals may be made electrical by rubbing them either on one another, or on non-metallic bodies. When disks of different metals are taken, it is found that there is a certain fixed order that determines which becomes positive and which negative. Thus, in the following series, each metal is negative when rubbed on any one following it, and positive when rubbed on any one preceding it:—bismuth, palladium, platinum, lead, tin, nickel, cobalt, copper, gold, silver, iridium, zinc, iron, cadmium, arsenic, antimony. Supposing we were to take a surface of platinum and a surface of iron, the platinum would be negative, and the iron positive; and so on with any other pair we choose to select. To produce the strongest possible indications of excitement, it is necessary to rub quickly with large sweeps, that the parts exciting one another may be separated as soon as possible; the farther the separation, the less the disposition of the two excitements to join again at the place of contact. When the agitation of the surfaces is produced by throwing the powdered particles of a metal on a plate of the same, the effect is like that of pressing or rubbing an unpolished on a polished surface—the powder is positive, and the plate negative.

115. In general, when bodies are rubbed on one another, the one which suffers the greatest agitation of its particles is negative; so that roughness, high temperature, and extent of rubbing, all increase the negative tendency. If two white silk ribbons, taken off the same piece, are rubbed across one another, the one that is moved in its whole length across the breadth of the other will be positive; and the other, which has experienced the most intense action, will be negative. The heat evolved will also be greater in the one rubbed across, and this will add to its negative character. If a white ribbon is rubbed on a black, and if the friction is equal on both, the first will be positive and the second negative, showing that the black dye causes the particles to experience more agitation, or else become hotter than in the white ribbon.

116. The tension of the electricity increases with the pressure and the rapidity of the motion. But there is a limit to the tension which can be produced in any machine; for the tendency of the opposite electricities to come together, and make a discharge at the place of their origin, increases as the tension increases, and at last becomes as great as the power employed to separate them.

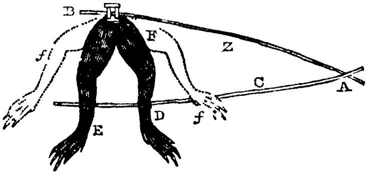
4th, Change of Temperature.—It has been observed that the tourmaline showed electrical excitement while in the act of heating or cooling, whereas it is perfectly free from electricity while remaining at the same temperature. It always possesses two poles opposite in their excitement; by heating, these display a certain polarity, which in cooling is reversed. The development of the electricity seems to result more immediately from the expansion and contraction caused by change of temperature. The topaz, boracite, and several other minerals, have the same property.

117. The production of electricity by heat constitutes a separate branch of the subject; namely, Thermo-Electricity. Chemical actions are also sources of electricity, but the consideration of these belongs more to Current Electricity than to the present head. The sources above given are such as yield the intense and Stationary excitement whose characteristics we have hitherto been engaged in describing.

VOLTAIC ELECTRICITY.

118. Galvanism was the name first given to the electricity produced in constant currents, feeble in intensity, and great in quantity; but it is now agreed that the discoveries of Volta (and not of Galvani) were what really constituted the foundation of this science; it is therefore entitled Voltaism, or Voltaic Electricity.

119. The original experiment of Galvani that excited attention upon this subject, consisted in convulsing the legs of a frog, by making a circle with two metals, and the leg between them. Thus, in the figure, EFD are the legs of a frog, Z is a rod of zinc connected with the nerve which ramifies in the legs, and C a rod of copper touching the rod of zinc at one end and the muscles of the two legs at the other. The circle is thus composed of four parts—zinc, copper, muscle, nerve. When the circle is completed by bringing the two rods into contact at A, after their other ends have been properly connected with the limbs, a convulsion takes place; the sudden contraction of the muscles throws the legs out into the position *ff*. But the very same effect is produced by a discharge of common electricity passed through the nerves and muscles of a limb: hence Volta declared that, in the case of the two rods, a current of electricity was generated; and he inferred from the circumstance that the contact of dissimilar metals was a source of electricity; and, working on this idea, he originated the voltaic pile, which is a series of pairs of plates of dissimilar metals, with a moist substance between each pair. He asserted, further, that the bare contact of the metals is the exciting cause of the electricity: but this has been disputed and denied; and it is maintained in opposition, that a chemical action of some sort is the origin of the electric current. The latter supposition, if it does not explain everything, is at least the most tenable of the two; and we shall therefore commence by enumerating the various chemical actions which lead to the production of currents.



120. If we plunge into nitric acid, one after the other, the ends of the two wires connected with a voltaic electrometer (to be afterwards described), electrical excitement is made apparent. The wire first immersed is seen to have positive electricity, and the other negative. If both were immersed at the same instant, probably no electrical action would arise; but the successive plunging causes the first to be oxidised, while the other is as yet untouched, and the difference of the acid's action on the more and less oxidised wires suffices to give birth to an electric current. This may serve as an example of the circumstances that determine whether a chemical action shall evolve electricity or not; it coincides, moreover, with what has already been stated as to the necessity of some inequality in the kind of materials used in order to bring forth an excitement.

121. When an acid combines with an alkali, the acid acquires positive and the alkali negative electricity. Thus if a platinum capsule, containing a solution of caustic potash, is put in connection with one wire of the electrometer, and if a piece of platinum, connected with the other wire, is moistened with nitric acid, and plunged into the potash, there appears instantly the indication of a current, such as to show that the capsule with the alkali is negative, and the slip of platinum with the acid positive. Thus one of the most common of chemical actions is a distinct source of electricity.

122. But solution, apart from chemical combination, is a source of electricity. If nitric acid is brought into contact with muriatic (or hydrochloric) acid, there is no chemical combination in the highest sense, there is merely solution (as when alcohol is mixed with water); yet a current arises, and the nitric acid is positive and the other negative. Phosphoric acid is positive to all the other acids, as well as to alkaline solutions. When acids are dissolved in water, they are positive and the water negative; when alkalies are dissolved in water, they are negative and the water positive: so that water is like an alkali to acids, and like an acid to alkalies. The apparatus for developing the current in these cases is the capsule and platina-slip already mentioned: the capsule contains the water, and is connected with one pole of the voltaic electrometer; the acid or alkali, if solid, is held by a platinum pincers connected with the other pole, which is plunged into the water. If the acid and alkali are liquid, a piece of spongy platinum is used, and dipped in the liquid, and then plunged into the water.

123. The case of what is called double decompositions of neutral salts, where two salts decompose one another, and exchange acids and alkalies, making two new salts, is remark-

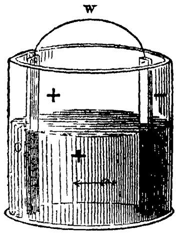
able for giving rise to no current of electricity, provided the quantities are exactly proportional, so as to leave no excess of any element. There can be no doubt that electricity arises in some of the stages of the operation of decomposing and combining, since either of these actions separately always yields excitement; it must therefore happen that the electricities evolved exactly neutralise each other.

124. Since simple solution, as well as chemical unions, gives rise to electricity, it is necessary to discriminate in individual cases which of the two has actually produced a given current. This discrimination can be made, on the ground that a chemical union always evolves heat, and raises the temperature of the mass; whereas dissolutions generally cause cold, and lower the temperature. A delicate thermometer may therefore indicate which of the two actions has happened.

125. In the action of acids and alkalies upon metals, there is apt to be a complication of effects. The simple action of an acid upon a metal is like that of an acid on an alkali; the acid is positive, the metal negative. But when an acid dissolves a metal, there is always the additional effect of the action of the newly-formed substance upon the liquid which the metal is immersed in; this may be of the same character as the action on the metal, and may therefore strengthen the resulting current, or it may be opposite, and weaken it. When there are two metals employed in one circuit, if both are acted on, their effects will contradict each other; and the result will be only the difference of the actions: hence in the voltaic circuit, which commonly consists of two metals and a liquid between them, it is requisite, in order to produce the highest effects, that the one should be acted on and the other not. And in general, the great art in combining several chemical actions to evolve electricity, is to make all the excitements that occur agree with, and not oppose, each other.

126. If two different metals are plunged into the same liquid, the one will probably be more attacked than the other; hence the one most attacked will be negative, and the liquid positive, which will render the other metal positive likewise, in spite of its own tendency to become negative. Now, as the metals differ very much in the quality of being acted on by acids—some, such as zinc, tin, and lead, being very rapidly and powerfully combined, and others, like platinum, gold, and silver, resist chemical action—it is desirable to choose two metals from the opposite extremes. Thus zinc is chosen for the negative metal, and platinum for the positive, in order to yield the greatest amount of action. Copper, although far inferior in resisting power to the precious metals, is yet greatly

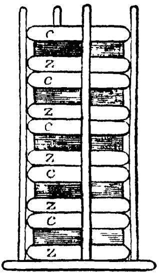
superior to zinc, and its cheapness causes it to be much used for the positive element of circuits. Thus, in the figure, let *z* represent a plate of zinc immersed in a liquor capable of acting on it, and *c* a plate of copper; the liquid will combine with the zinc, and give it a negative electricity, and be itself positive; the copper will also be acted on, but more feebly: and hence, instead of being negative, it will receive a positive excitement from the intervening liquid, and act as a conductor to carry round the positive current. When the plates have no connection outside of the liquid, each is attacked according to the degree that it yields to the agency of the liquid; but when the circle is completed by the wire *w* joining the unimmersed ends of the plates, the zinc is more attacked than before, and the copper less attacked. The carrying round of the electric currents causes this effect.



VOLTAIC CIRCLES AND BATTERIES.

127. If a disk of copper and one of zinc are taken, and a wet cloth put between them, electricity will be produced—the zinc will be negative, and the copper positive: if a wire is brought from the zinc to the copper, an electrical *current* will be established; the positive electricity flowing from the zinc through the moist cloth to the copper, and along the wire to the zinc again; and negative electricity flowing in the opposite way, or from the zinc round the wire to the copper, and from the copper through the cloth to the zinc. The apparatus is in principle the same as that figured in the preceding article. Such a combination of zinc, wetted cloth, and copper, makes a couple, or single circle of Volta. The cloth is moistened with water containing a small quantity of acid or salt.

128. The pile of Volta is an aggregation of these simple circles, so ordered that the same currents flow in the same direction in them all. Thus to build up the pile, let an upright stand be formed with glass or wooden rods ending in a bottom: place on the bottom a disk of zinc *z*, then a wet cloth, then a disk of copper *c;* upon the copper lay another series of zinc, cloth, and copper, and so on for any number, the pile terminating in a disk of copper above, as in a disk of zinc below. The zinc end will be negative, and the copper end positive; and if a wire is passed from the zinc to the copper,



the circle is said to be closed. Its action then rises to the highest pitch, and currents of the two electricities circulate around. The lowest zinc, itself negative, renders the moist cloth above it positive, which transmits a positive current to the copper; the copper passes this to the next zinc, which transmits it by conduction, along with what itself generates, to the second cloth; the double force is passed to the second copper, and by it to the third zinc, which the copper touches; the third zinc communicates it to the third cloth, increased by its own action on the moisture of the cloth, and thus a threefold charge is carried to the third copper, and so on. On the other hand, a negative current of equal strength circulates downwards, augmented at each step in the same manner; for the lowest zinc plate, while originating a positive charge proceeding to the copper above it, sends a negative charge the other way; that is, by the conducting wire that goes from it to the uppermost copper, which transmits it through the wet cloth to the uppermost zinc, where another of the same is produced and sent downwards. Thus a double negative charge is passing down through the cloth second from the top to the second zinc, there to be reinforced, and sent to the third, and so on. The surface of contact of a plate of zinc and a film of liquid, is always understood to be producing the two electricities, and sending one off in one direction, and the other in the opposite; just as at the contact of the cylinder and cushion in the electrical machine.

129. By such a pile the various electrical effects can be visibly produced. When the wires attached to the two ends are brought together, a spark may be seen. A shock is felt by passing the current through the body, which is done by holding a wire in each hand. Heat is also produced at the ends of the wires where they touch. But to make the effects decided, a very large pile must be formed, extending perhaps to a hundred pairs or circles, each disk being the size of a crown-piece.

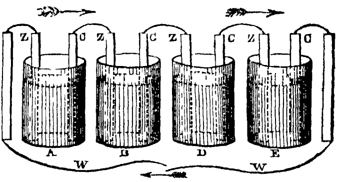
130. The peculiarity of the excitement of the voltaic pile, and of voltaic currents generally, is their feeble intensity. This is the point of contrast between Voltaic and Tension Electricity. When a metallic surface, such as the coating of a Leyden jar, is electrified by the machine, the separation of the two kinds is carried very high, so that their tendency to come together is intense and violent. The standing accu-

mulation at the two ends of a single polarised particle is greater in machine-electricity than in any other kind. If we take a particle of copper in the plate of a voltaic circuit, and a particle of tinfoil in the coating of a Leyden jar, the second is immensely more charged than the first. The distinguishing character of the voltaic electricity is *quantity*. A large amount of excitement of a feeble kind is generated, and passed round the circle. Instead of highly charging the superficial particles of a metallic surface, it charges the entire solid mass with a low intensity, perpetually renewed as it is taken off. If the current is resisted by insulation, the action does not go on heightening the tension of the charge, but stops altogether. When this difference in the mechanical character of the electricities of friction and contact is allowed for, they can be proved to be identical in their nature and effects.

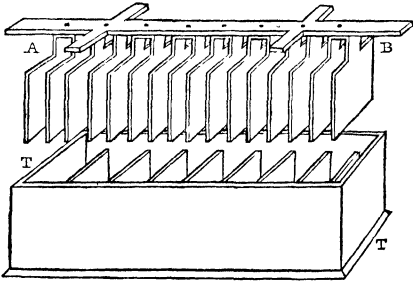
131. The intensity of voltaic electricity is greatest when the pile is made up of a very great number of small plates. Supposing an equal amount of surface of copper and zinc employed, the shock, and other indications of a strong charge, would be greater if it were cut up into many small circles, than if it formed a few large ones. But the actual quantity of the excitement would be greatest with the large plates. We shall afterwards see that chemical and magnetic effects are the measures of quantity independently of intensity. The two qualities may be compared to heat of different temperatures. A tubful of water at 100 degrees has a greater quantity of heat than a cupful at 200 degrees; but the latter is the more intense of the two. The cause of the greater intensity in the long pile of many plates, is the resistance offered by the length of bad conductors through which it passes; but from the intrinsic feebleness of the exciting action, this resistance diminishes the quantity that could be evolved. The presence of the excitement already produced is always a bar to the evolution of new excitement. If the exciting force be of a certain power, it will go on raising the tension till the latter has become so strong as to equal the force; at this point the action must cease, or the opposed electricities will be combined as fast as they are formed, if they are formed at all.

132. As the pieces of cloth between the zinc and copper of Volta's circles are of no use but to contain the acting substance, they may be dispensed with, and the plates inserted in a vessel containing the proper kind of liquid. Volta, accordingly, made an arrangement that he called the "couronne des tasses" (the crown of cups); which consists of a row of cups or jars filled with acidulated water, and each containing a

couple of plates. Thus let A, B, D, E be four jars half-filled with liquid. Into the first is placed a zinc plate Z, and a copper plate C; if these were connected, a current would arise, as was formerly described. But instead of connecting these, let a wire pass from C to Z, a zinc plate in the second jar, which contains also a plate of copper connected with the zinc of the third jar; and in like manner the copper of the third is connected with the zinc of the fourth; the copper of the fourth would connect with the zinc of a fifth; and so on. Let a wire W proceed from the copper at one end, and come into contact with a wire from the zinc at the other; the circle is closed, and the action circulates. From Z to C in the first jar A, there passes through the liquid a positive current, which is carried by the conducting wire to the second Z, and at Z's contact with the liquid joins a second charge, and both pass on to C, exactly as we described in the pile. In the opposite direction a negative current will proceed, reinforced, like the other, at every plate of zinc.

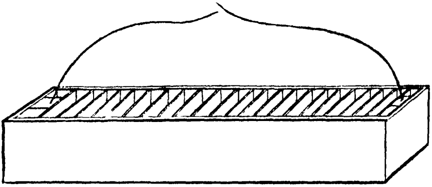


133. A more compact apparatus on the same principle is that called the Trough Battery. A trough of porcelain T T is divided by partitions into separate compartments or cells, each cell being intended to answer the purpose of one of the jars, or contain a pair of plates. The plates are suspended in a piece of wood A B, at the proper distances, and connected with one another by metallic slips. The battery of the Royal Institution, made under the direction of Sir Humphry Davy, and used by him for his celebrated discoveries of the compound



nature of the alkalies and earths, was of this form; it consisted of 2000 double plates, and its acting surface amounted to 128,000 square inches.

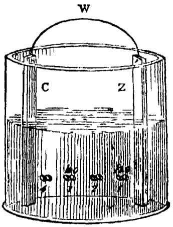
134. Another kind of trough is formed by making the partitions themselves the acting plates. A plate of copper and a plate of zinc are soldered together, and each compound plate makes a partition wall, the liquor being contained between them.



135. Dr Wollaston effected an improvement on the galvanic trough battery by making the copper plates double, so that each enclosed a zinc plate, and faced it on both its sides. The action on the zinc is very much increased by thus enlarging the copper; for it is found that the energy of the circle depends not only on the metal attacked, but on the conducting metal. The greater the conducting surface, and the nearer it is to the zinc, the more intense and rapid is the combination of the liquid with the zinc. In the circles made up of a single plate of zinc and a single plate of copper, the zinc is acted on only on the side facing the copper; but by Wollaston's arrangement, both sides are made to produce currents. The case is exactly analogous to single-surface electricity, where the charge taken in is entirely dependent on the capacity of surrounding surfaces to receive an opposite charge by induction. In so far as zinc is acted on by mere ordinary chemical action, the size and distance of the copper plates are of no moment; but the increase of action arising from the current in a closed circle, is in proportion to the quality and size of the metallic plate that serves as the conductor.

136. All the batteries above described have one especial imperfection among many others; which is, that from the moment they are set in action, their strength constantly decreases. At the end of an hour, or two hours, their power is almost reduced to nothing. This is owing to the reaction on the plates of the products of the chemical combinations. It is therefore a great object to construct *constant*[1] *batteries* (as well as to arrange the elements so as to prevent the rise of

conflicting currents), and otherwise to heighten and economise the force of the battery. But the nature of the schemes which have been adopted for these ends cannot be understood without attending more closely than we have yet done to what goes on in the voltaic circuit.



137. Let us consider again a single copper and zinc pair immersed in a liquid; and let the liquid in the first place be pure water. Let *z* and *c* be the two plates, and suppose a row of water particles to lie between them. Each water particle is a compound of a particle of oxygen and a particle of hydrogen; and it is almost certain that the following process is gone through when the conducting wire *w* arches the two plates, and closes the circuit. A particle of water (1) is attracted to the zinc by its oxygen constituent; the affinity of the zinc for oxygen surpasses the affinity of hydrogen for oxygen, and the effect of this is to decompose the particle, and form a particle of oxide of zinc, and leave a particle of hydrogen, producing at the same time a certain amount of free electricity; the oxide of zinc having a negative charge and the hydrogen a positive charge. The negative charge of the oxide of zinc passes on through the metal plate *z*, the positively charged hydrogen is attracted to the oxygen of the next particle of water, and its electric state adds to its natural attraction for this atom of oxygen, and accordingly it overpowers the existing attraction that keeps the two elements together, combines with the oxygen, and sets free the hydrogen of No. 2. But this decomposition evolves a new charge of electricity, the water particle being positive and the hydrogen negative. A third particle of water is decomposed in the same way, and a fourth; and so on till the plate of copper is reached. The last particle of freed hydrogen encountering it can decompose no further; it communicates its excitement by contact to *c*, and rises up to the surface, and is dissipated in the air; so that the conduction through the water is effected only through a series of decompositions and combinations, showing the mode whereby liquid particles receive and transmit polarity. The influence evolved at the zinc is necessarily weakened by having to operate so many actions; and it is found that the greater the distance between the two plates, the weaker the current is. Even if nothing were absolutely lost at the transmigration of each water particle, there would be a delay, from time being necessary to all motions, even the quickest; and delay would be resistance.

138. It is found that a circle charged with pure water, such as the above, is very weak, and soon ceases; but if a small quantity of sulphuric acid is added, its energy is renewed and quickened. The oxide of zinc formed on the plate stands between the water and the pure metal, and the action is thereby arrested; but the sulphuric acid combines with and dissolves this oxide, and exposes a clean surface for the further action of the water. But the combination of the sulphuric acid with the oxide of zinc is itself a source of electricity of the same kind as the water action—that is, it makes the zinc negative and the liquid positive; this is, therefore, an addition to the force. But an unfortunate drawback belongs to the acid action. The dissolved sulphate, by being made positive, has an attraction for the copper plate; for this plate, while receiving a positive excitement from the zinc through the liquid, is returning or radiating forth a negative current through the zinc, thus presenting an attraction for all positive elements as well as for the hydrogen. The sulphate of zinc is therefore drawn towards it; and as it cannot go off in air bubbles like the hydrogen particles, it sticks and deposits a coating on the plate, which mars its conducting power; so that what was good in the beginning is in the end an evil.

139. Another source of weakness occurs in the contact of the hydrogen with the copper. The attraction of these two elements is essential to the maintenance of the current; but the same attraction that brings the hydrogen close keeps it there, and constitutes a resistance to the succeeding portions. It would be well that the hydrogen could be got rid of the moment it touches the copper, instead of adhering and stagnating, and occupying the ground which other particles are pressing forward to seize. Now it is found that the addition of nitric acid to the sulphuric acid and water, serves to absorb the free hydrogen, and in this way proves an accession to the strength of the current. But the addition of any new ingredient leads to a new series of actions, both from its chemical agency and from its contact with the other elements of the solution; these new actions being sometimes with and sometimes against the general current. By using sulphate of copper alone, in addition to the water, the hydrogen may be absorbed; the sulphate will be turned into sulphuric acid, and copper, which the hydrogen displaces, deposited on the copper plate, thus maintaining a clean and ever-renewed copper surface. The hydrogen, when not absorbed in such a way as this, is very apt to act upon the compound of zinc dissolved in the liquid, and reduce it upon the copper plate, making a second zinc surface, whereby the action must soon come to

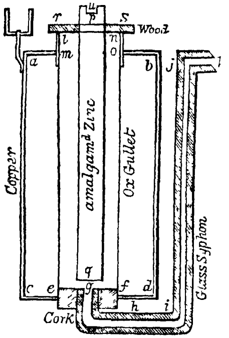
a stand altogether; for two identical plates can yield no excitement.

140. In the forming of constant batteries there are two improvements which have been of especial value. The first is the amalgamation of the zinc, or the coating of it with mercury, thereby presenting a combination of zinc and mercury instead of pure zinc. This is found to diminish to an extraordinary degree the waste of the zinc, or to produce an equal amount of electricity by a much smaller consumption of the acting metal. It is not well understood in what way the mercury contributes to this effect. We have a parallel to it in the rubber of the electrical machine, which is an amalgam of zinc and tin, and far surpasses in effect any other material that could be used; but in neither case is it clearly known what action goes on. The only supposition that has been made as to the way in which the mercury saves the zinc in the voltaic circle, is that it takes away local currents—that is, the naked zinc plate is conceived to produce currents which come round to itself instead of proceeding to the copper, and thus detract from and contradict the general effect.

141. The second great improvement in batteries is the use of *diaphragms*, or porous and permeable partitions between the zinc and copper. These are intended to prevent the dissolved zinc from passing to the copper plate, to be precipitated or reduced there. The partition must, however, allow a free contact of the liquids on each side of it, otherwise it would arrest the action altogether. Many kinds of material have been tried as diaphragms, it being somewhat difficult to find a substance which will allow the liquids on each side to be in contact within its pores, and at the same time keep the one from passing through to mix with the other; besides having other virtues, such as not to become closed up by the precipitation of the salts, not to contain bad conducting material, and not to produce currents from the action on their own ingredients. Bladder, tanned leather, pasteboard, cloth, thin slices of wood, clay, porcelain, &c. have been used, and each has its disadvantages.

142. The *Constant Battery*, introduced by Professor *Daniell*, is constituted as follows:—Each cell or separate circle is of the form of a cylinder, whose construction will be understood by the figure, which is a section down the middle: *a b c d* is the outer cylinder made of copper; it is open at the top, but closed at the bottom, except that there is an aperture *e f*, which receives a cork containing the end *g* of a glass syphon tube *g h i j k*. On the top *a b*, a copper collar *l m o n* rests upon two horizontal arms *a m*, *b o*. Between this collar and the cork

neck at the bottom, a cylindrical diaphragm is stretched, made of ox-gullet, and forming an internal cavity connected at the bottom with the syphon outside. In this cavity there is placed a rod of amalgamated zinc *p q*, suspended from *r s*, a piece of wood lying over the rim of the diaphragm. Into the same inner cavity of the diaphragm is poured acidulated water, which surrounds and acts on the zinc; around the diaphragm, in the outer cavity, there is contained a solution of sulphate of copper. The action of the cell is this: the acidulated water acts on the zinc rod, and excites electricity, at the same time dissolving the zinc, and forming a salt of zinc within the diaphragm; this, from its being heavier than the other liquid, sinks to the bottom, and passes into the syphon, and is carried off if new liquor be added from above to give a sufficient pressure. In this way the product of the action on the zinc is got quit of. The voltaic current is freely allowed to pass through the membrane to the outer cell, and deposit hydrogen on the copper cylinder; which hydrogen, acting on the sulphate of copper, is absorbed by it, and displaces metallic copper, which is deposited on the cylinder, the sulphate being converted into sulphuric acid. A coating of its own substance is thus continually forming upon the copper cylinder, keeping it always fresh and new. To renew the waste of the sulphate of copper, a few solid crystals are suspended in connection with the liquor of the outer cell, which are dissolved as they are required. A battery formed of such cells is found to maintain its strength without diminution for many hours; it also prevents many of the sources of waste of power that were present in former batteries. The power of the battery is found to increase with the temperature; but to work it at a high heat, a porcelain diaphragm must be substituted for the ox-gullet. In subsequent batteries the syphon was disused.



143. A rod of zinc, in a cylinder of copper, is the best form for producing the greatest possible action on the zinc; the latter is confronted all round with a surface of copper, and is therefore acted on equally on every side. A rod and cylinder could be surpassed only by a ball in a hollow sphere, which would not be so convenient.

144. Batteries have been formed by circles where the copper and zinc were rolled up in a spiral, thus affording a large surface in a small solid bulk. It has already been mentioned, that in order to get the electricity in greatest possible quantity, circles of large surface are chosen.

145. *Grove's Battery* is of the same general construction as Daniell's; but instead of copper, platinum is employed, which, being of all metals the least oxidisable, makes the best conducting plate for a circle. Zinc and platinum form the most powerful couple that can be used. Accordingly, Grove makes the outer cylinder of the circle of platinum, and the diaphragm or intermediate cylinder of porcelain, which contains the amalgamated zinc rod. The outer cavity between the platinum and porcelain cylinder is filled with nitric acid, and the inner cavity around the zinc with dilute sulphuric acid. A very powerful current is generated by this arrangement; and although of an expensive construction, from the employment of platinum, it has come into general use. The action is of the same nature as in Daniell's circle. The zinc is oxidised and the oxide dissolved in the sulphuric acid; sulphate of zinc being thrown down, but confined by the partition within the inner circle. The positive current passes from the inner to the outer liquid, and hydrogen is evolved at the platinum, and taken up by the nitric acid. There is no metallic deposit of any kind; but both liquids are changed by their actions, and require to be renewed from time to time.

146. The principles which determine the quantity of electricity evolved in a circle or battery have been reduced to precise mathematical theorems by Professor Ohm. The following are the general statements on which the theorems are founded :—

1*st*, The quantity of the current depends on the tension or strength of the electricity, and on the goodness of the conductors, or the absence of resistance to its passage.

2*d*, The strength and quantity of the current depend, in the first place, on the material used in the circle: the greater the affinity of the acting plate for oxygen, and the less the affinity of the conducting plate for oxygen, the greater the action. In the second place, the result increases with the size of the plates, particularly the conducting plate; it is of no use to increase the zinc surface if the copper or platinum surface remain the same.

3*d*, The resistance in the circle is, first, that of the fluid conductors in the cells; and second, that of the solid conductors, or the wires that close the circuit. The smaller these resistances the more powerful the current.

4th, The resistance of the fluid is in proportion to the thickness of the layer between the plates. By placing the plates very near, the enclosed liquid is so much thinner, and less resisting.

5th, The resistance in passing through the wires is as their length, and as their thinness. The shorter and thicker a wire is the more easily does the current traverse it.

6th, The tension or strength of the electricity increases with the number of the plates. If the plates are few and large, the quantity that could be produced is very great; but if there be much resistance, it is completely checked. Hence if the circuit is closed with bad conductors, or if the wires are long and thin, a battery of many plates is necessary; but if the circuit is closed by good conductors, and the resistance in every way small, a few plates will maintain the current, and produce it in considerable quantity.

147. The conducting powers of the metals themselves are very unequal, supposing them made into wires of equal sizes. The following table expresses the comparative powers of several of them:—

Silver,	136	Platinum,	22
Gold,	103	Iron,	17
Copper,	100	Mercury,	2·6
Zinc,	28		

Thus a copper wire of 100 feet offers the same resistance as a silver wire of 136 feet, or an iron wire of 17, all of equal thickness. Hence in considering the resistance offered by the solid parts of the circuit, the material that it is composed of must be attended to.

148. In like manner, there are great differences in the conducting powers of liquids. Distilled water is very weak compared with saline solutions, alkalies, and acids; but the best of liquid conductors are very feeble compared with the metals.

EFFECTS OF VOLTAIC ELECTRICITY.

149. The voltaic current may produce Heat, Light, Chemical Decomposition, and Mechanical Power, as well as actions on the Animal Frame.

150. The production of *heat* takes place when the current is resisted, but not entirely checked. Thus if the circuit be closed by a bad conductor, and the tension high enough nevertheless to force a current through, the resisting portion is intensely heated. It is a general rule, that when electricity is interrupted, it passes into heat. Thus if a powerful pile is

closed by a thin wire, the latter is very soon turned red-hot and melted away. If gold leaf is made a part of the circuit, it is quickly heated and volatilised. Platinum, which cannot be melted by the heat of ordinary furnaces, yields to the voltaic pile. Iron and steel wire are melted and burned with the emission of brilliant sparks. Thus electricity is one of the means of producing very high degrees of heat. In this action upon bad conductors we have one of the links which associate electricity and heat: a simple mechanical circumstance suffices to convert the one into the other. The relative conductibilities of metals and other bodies can be experimentally determined by observing their rise of temperature when a current is transmitted: that which becomes hottest is set down as the worst conductor when other circumstances are alike.

151. The fusion of all the metals, as well as of many of their mineral compounds, can be effected by passing powerful currents through them when they are attenuated into leaves or fine wire.

152. *Light* can also be produced by the voltaic circuit, sometimes of very great brilliancy. The circumstance of its appearance is the same as in machine electricity; namely, a disruptive discharge through a bad conductor. Of course when bodies are highly heated they become luminous, as a mere consequence of the heat. The metals, when made red-hot, or burned by electricity, have exactly the same luminous appearance as they always have when subjected to the same heating action. The instant that a circuit is closed by bringing the wires together, a spark is seen at the joining; and if, after contact, the ends of the wires are kept at a little distance, a constant stream of sparks passes between them. But the greatest brilliancy of light is caused by making the wires end in pieces of charcoal, and bringing the points of the charcoal together. A dazzling spark is now produced; and if the pile be powerful, a brilliant stream may pass from one point to another, while they are held a little way apart. In the course of the action, the charcoal points are worn away; a stream of particles constantly flows from the one to the other; and the light issues from these particles, as the white light of a gas flame comes from the particles of carbon which are thrown out into the flame, and remain there red-hot for an instant before being burned. When sparks are passed between metallic wires or balls, it is found that the surfaces are scathed, as if their outer particles were torn off and sent in a shower through the blank interval between the two. The disruptive discharge is always productive of mechanical violence and heat, both on the surfaces of the conductors and on

the substance of the intervening dielectric, and this may be the primary cause of the spark.

153. The *chemical action* of the pile in decomposing compound substances is the most important of all its effects, and is such as to render it a great chemical agency. The electric circuit is a medium whereby the power evolved when two bodies combine can be carried to a distance and made to separate a combination, or reduce a compound to its elements. This power was discovered in the beginning of the present century by Carlisle and Nicholson. The first substance decomposed was water, which had been previously shown to be a compound, by producing it from oxygen and hydrogen burned together. The inverse process of reducing the water to its separate gases had not been effected before. If the two wires of a battery are immersed in water at a little distance from one another, bubbles of gas appear at each. The gases may be collected by glass bells (adapted to the collection of gases) being placed over each wire. The wires are formed of platinum, which has no affinity for either gas; if they were of iron, the oxygen would combine with the point of the wire on which it is evolved, and form an oxide. The quantity evolved will increase as the wires are brought nearer; and it is increased still further by substituting metallic leaves or thin strips for the wires. Oxygen always rises at the positive wire, or the wire from the copper or platinum end of the battery; and hydrogen at the negative, or the wire coming from the zinc end. The bulk of the hydrogen produced is twice that of the oxygen, which is in accordance with the proportions which combine together to produce water.

154. The action which takes place in the water by a current of electricity passing through it, is a series of decompositions and combinations exactly like that described as occurring between the copper and zinc in the cell. The positive wire attracts a particle of water by its negative atom, the oxygen, and with a force that overpowers its attraction for the hydrogen atom, which is set free with a high negative charge; by this charge the hydrogen acts on the next oxygen atom, and draws it away from its hydrogen, making a new particle of water. The hydrogen, now set free, goes to a third water particle, and decomposes it; and so on till the other wire is reached, which, being highly positive, the hydrogen ultimately comes upon it, and is carried off, so that although decomposition passes all through, the gases are set free only at the wires. Here, then, we have the electricity given forth by the combination of zinc with oxygen in the cell, passed along and expended in overcoming the affinity of the two

elements of water for each other. In this case we may say that electricity and chemical affinity are one and the same thing; the electricity is, in fact, nothing else than chemical affinity set free and conducted round a circle in a current, to act as such in another place. The remarkable thing is, that the chemical polarity is transmissible through metallic conductors, as well as through compound substances, where it acts strictly in its own character.

155. When Sir Humphry Davy had constructed the Royal Institution's large battery of 2000 plates, he applied it to the decomposition of bodies, and discovered that the alkalies, such as potash and soda, resolved themselves into oxygen and a metal. The earths (lime, for example) were similarly decomposed. The discoveries of Davy have been extensively followed up, and the conditions of electrical decomposition accurately ascertained. It is not all compounds that can be decomposed by the voltaic battery.

156. The term *electrolysis* is applied to decomposition by electricity; *analysis* being the term used by chemists for ordinary decomposition. Bodies which can be decomposed by the current are called *Electrolytes.*

1*st*, The first principle of electrolysis is, that the compound must be in a *liquid* state. Solids are not decomposable. Ice, for example, resists the most powerful currents. Hence if a solid body is insoluble, it must be melted, and in that state held between the poles of the battery.

2*d*, The second principle is, that the elements always take a definite direction. The oxygen goes uniformly to the positive pole, and hydrogen or a metal to the negative. Upon this tendency substances are classed and set down as positive or negative in character, according to the pole to which they go. Thus oxygen being attracted to the positive pole, is reckoned an electro-negative substance; hydrogen and metals electro-positive. When a salt is decomposed, the acid goes to the positive pole, the base to the negative. If sulphate of copper, for example, were taken, sulphuric acid would appear at the positive pole, proving itself to be electro-negative like oxygen.

3*d*, In the third place, the chemical actions are equal to one another; the combination which originates the electricity is exactly equal to the decomposition that it can cause. A certain amount of zinc, oxidised and dissolved, will yield an equivalent amount of decomposing force; or should, if the conduction were perfect, decompose exactly the same quantity of oxide of zinc. When substances are combined together in chemical union, there is generally an evolution of heat or electricity, as if less of these was required in the compound than is contained in the substances in their separate state. Accordingly, when a compound is decomposed, whatever was given out at the time of its formation is taken back again; so that while combinations give forth certain influences, decomposition absorbs these. And in the voltaic circuit, it is found that the decomposition between the wires is exactly measured by the amount of material consumed in the cells, according to the scale of atomic proportions. It is precisely analogous to the case of what is termed *the double decomposition of salts.*

4th, None but simple compounds can be decomposed. Complex compounds, such as sulphuric acid, nitric acid, peroxides, and perchlorides, are not decomposable by the current. Protoxides and protochlorides, or the combinations of metals with the lowest proportion of oxygen and chlorine, represent the decomposable substances. Chlorine, like oxygen, is an electro-negative element: when it has been combined with hydrogen (hydrochloric acid), or with a metal, it is evolved at the positive wire of the circuit. The elements of hydrochloric acid are sometimes used to designate the two constituents of an electrolyte: the atoms that pass to the positive pole are called the *chlorous* molecules; the others, which pass to the negative pole, are called the *hydrous* molecules.

5th, The affinities of the most opposite substances are the most liable to be overcome by the electrical current. Thus oxygen and the metals are reckoned intensely opposite in their character, and by virtue of this opposition, their chemical affinity (which is regulated on the principles of polarity, where opposites attract) is intense; and the action of electricity in counteracting this affinity is also decided. Chloride of sulphur, which is a compound of elements not much opposed to each other, is not decomposed by electricity.

157. The *shock* of the voltaic pile differs from the discharge of a Leyden jar; the electricity of the pile being of feeble intensity, it does not give the blow received from the jar. The greatest shock is derived from the pile of many plates. If, after moistening the hands in salt water, to heighten the conducting power of the skin, we grasp the two wires, one in each hand, a shock is felt at the first contact, and then a heating current up the arms, and a tingling sensation in the hands. A shock is also felt at the separation, arising from the sudden return of the polarised fibres of the arms to their natural state. If the tongue is placed between two wires, or between a piece of zinc and a piece of silver which touch one another, a bitter taste is felt. When a current passes in any way through the eyes, a flash of light is seen. When strong

voltaic batteries are discharged through the bodies of animals recently dead, their limbs and features are convulsed and made alive in a hideous way. Experiments have been made on executed criminals, which showed that electricity could in some degree act the part of the nervous currents in moving the bodily organs. By stimulating the nerves of the lungs, a laborious breathing was recommenced; by passing currents through the nerves of the face, the features moved and stretched themselves out into horrible grimaces; when one wire was connected with the hip and another with the heel, the leg, if bent, threw itself out with great force. In the same way the fist could be closed or the hand opened by touching the proper nerves with one wire and the points of the fingers with the other. These results are only extensions of the original experiments of Galvani.

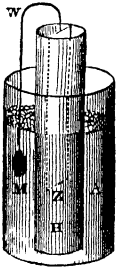
APPLICATIONS OF THE VOLTAIC CURRENT.

158. The first practical application of voltaic electricity to the arts, was the protection of the copper bottoms of ships from the destructive action of the sea water. Sir Humphry Davy suggested that nails or wires of zinc should be fastened at intervals on the copper plates, which would cause a circuit to be formed of copper, zinc, and salt water. In this case the copper would cease to be acted on by the water, and would serve as a conducting plate to the zinc, which would be the substance wasted. Thus a small expenditure of zinc would come in place of a great expenditure of copper. A piece of zinc, equal to the head of a small nail, was found sufficient to protect between forty and fifty square inches of copper. The value of the application was, however, neutralised by a consequence which had not been foreseen. The protected copper bottom rapidly acquired a coating of sea-weeds and shell-fish, whose friction on the water became a serious resistance to the motion of the vessel, and it was discovered that the bitter poisonous taste of the copper surface, when oxidised, acted in preventing the adhesion of living objects. The principle, however, has been applied with success to protect the iron pans used in evaporating sea water.

159. The greatest application of the voltaic circuit is the *Electrotype;* or the process of multiplying impressions of medals, coins, engraved plates, busts, &c. which was developed about the same time by M. Jacobi of St Petersburg and Mr Spencer of Liverpool. It is founded on what takes place in the circle of Daniell, where a solution of sulphate of copper is in contact with the copper plate, and deposits on it metallic

copper. If the original plate were of a certain form, the deposited plate would exactly fit it; and if the latter could be taken off whole, its surface would be exactly the reverse of the former. If the one were a coin in relief, the other would be a coin with a hollow impression. As the copper is deposited in a shower of the finest particles, it must completely enter all the depressions and lines of the plate, and form a surface so faithfully exact in its correspondence, that no human perception could discern a difference. The requisites of the process are, that the thing to be copied shall have a metallic surface, so that it may become the conducting plate of a circle—that something be done to prevent the coating from adhering too strongly to the original—and that the deposition should be so conducted that the deposited plate may have a close metallic texture.

160. The first discoverers confined themselves to the copying of metallic surfaces, such as copper plates and coins; but a method has been found of copying plaster of Paris, wax, wood, or any non-conducting substance, by covering the surface with black lead—a form of charcoal, which answers the purpose of a conducting plate.



161. The apparatus for copying a medal or coin consists of a cylindrical vessel, containing in it another cylinder of porous porcelain to serve as a diaphragm. Thus A is the outer cylinder; H is the diaphragm, which contains the zinc plate Z immersed in acidulated water. The outer space is filled with sulphate of copper, and in it hangs the original medal M, connected by an arching wire W with the zinc, and making a voltaic circle. The medal is covered over with wax or grease behind, and on the edges, or wherever the copper is not to be deposited. To prevent inseparable adhesion, the face is covered with a slight varnish. The action of the circle then precipitates copper on the naked surface of the medal, and goes on adding to it as long as may be desired. If the action is slow, the coating is so much the harder. To make a good impression of tolerable thickness, one or two days are allowed. If the hollow impression thus derived is put into the circle, and itself coated, a surface will be produced in relief, which will be a perfect fac-simile of the original coin. To save the double process of making first a hollow and then a relief, a cast of the original may be taken in wax or plaster of Paris, or other fusible material; this cast will then receive a surface of black lead, or of fine copper bronze, which can be laid on with a

brush. It is now a conductor, and may be inserted in the circle to receive a deposit, which will exactly resemble the original object.

162. To make gold or silver medals, solutions of salts of these metals must be substituted for the sulphate of copper. The surface deposited on requires also to be previously coated with gold or silver. The difficulty of the process is much greater with the precious metals. It requires a more powerful current to precipitate them. For silver, the solution may be nitrate, sulphate, or acetate; for gold, a very strong nitro-muriatic solution (chloride of gold) is requisite.

163. For copying engraved copper plates a larger apparatus is used: the circuit is completed with copper and zinc, like a Daniell's circle, and the deposition is made in a vessel apart, in the manner that decompositions are effected. Thus the vessel D D contains a cylinder of copper, whose place is marked by the waved lines E E; within this there is a porous cylinder O O O for a diaphragm, and within it a zinc cylinder Z Z, nearly filling the porous cylinder, but not touching it. The usual charge of liquids is applied without and within the porous partition. On the copper cylinder there rests a perforated cover S S for holding crystals of sulphate of copper, to keep the solution beneath in a state of saturation. Thus are supplied all the parts of a single circle. In a vessel apart, AB, lies the plate to be coated *b*, connected by a wire with the zinc cylinder of the circle. Another plate *c*, of oxidisable metal, faces it at a little distance, and both are immersed in the solution which is to furnish the metallic precipitate. The connecting wires proceeding from the plates in the circle are fastened tight to the wires from *b* and *c*, by screws X and Y, to make the conduction as good as possible. When the circle is closed, electricity is generated in the cylinder, and passed to the plates in the depositing vessel. The liquid between these plates is decomposed, oxygen is evolved at *c* the negative pole, and metal on *b* the positive pole. The plate *b* being prepared in the manner above described in reference to medals, by coating the back and edges with wax, to limit the deposition, and by varnishing the face to prevent adhesion, a reverse copy of its surface is procured. If the original engraved

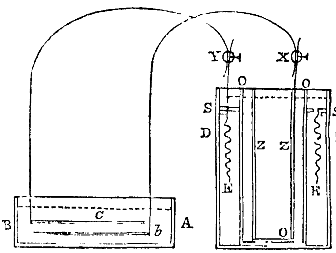


plate is employed, the plate formed from it when put into the apparatus, will be covered with a second plate identical with the original; or if a cast is first taken, an identical copy may be procured by one deposition. It is possible, by regulating the circle, to obtain a deposited plate superior to the engraved plate in the quality of the impressions which it gives when printed from.

164. The improvement thus effected in the art of engraving is very great. When a copper plate is engraved, and impressions printed off from it, only the first few, called "proof impressions," possess the fineness of the engraver's delineation. The plate rapidly wears and becomes deteriorated. But by the voltaic process, the original plate can at once be multiplied into a great many plates as good as itself, and an unlimited number of the finest impressions procured.

165. Another form of applying voltaic electricity to the plastic arts, is the *voltaic etching.* The ordinary process of etching consists in covering a copper plate with a coating of wax, and by a graving-tool cutting out the sketch in the wax down to the bare copper. The portions intended to be in relief are left covered, and those to be hollowed out are laid bare. The plate is then immersed in acid, which eats away the exposed surface to some depth, but is prevented from acting on what is covered with wax. The wax is then dissolved away, and there remains a sketch in relief of the engraver's design. But by the new process, the plate, after being waxed and sketched, is immersed in the depositing vessel of the circuit, and is coated with copper wherever the wax has been cut away; and in this manner a relief surface is given corresponding to the figure that was formed in the wax. This is the opposite of the acid action, which makes the hollows where the plate is laid bare; and therefore, in engraving the surface, an opposite course has to be pursued. The wax must be cut where relief is wanted, and left where the hollows ought to be.

166. A still further extension of the art of voltaic engraving has been proposed by Kobell of Munich, by which pictures drawn in Indian ink may be multiplied. A copper plate, silvered over, is used for drawing on. The colour is spread over the silver surface in such a way that the brightest lights are naked silver, and the paint is laid on according to the depth of the shadow, the strongest shadows having the thickest coating. The plate is then covered over with a wash of finely-pulverised black-lead, and put into the depositing cell, and a copper plate formed upon it. This plate will be in relief where the lights of the painting are, and hollowed in propor-

tion to the depths of the shadows. If it is now printed from in the manner of an engraved copper plate, it will yield impressions similar to an Indian ink drawing.

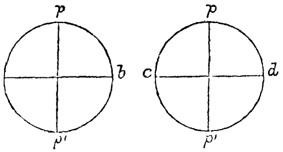
167. *Gilding* and *plating* are now performed very successfully by voltaic deposition. Any metallic surface can be gilded, or silver-plated, to whatever thickness may be desired. A platinum surface can also be communicated. In this way the precious metals can have their usefulness very much extended. Plants may, in like manner, be coated over with copper, and have their forms preserved for any length of time. So baskets and wickerwork can have a metallic surface communicated to them.

ELECTRO-MAGNETISM.

168. It had long been observed that electricity was capable of producing magnetic effects. The needles of ships' compasses, when struck with lightning, always underwent a change in their magnetic character: on some occasions their poles have been reversed, what was the north before becoming the south. Disturbances of needles have also been caused by shocks from Leyden batteries. It was thus generally supposed that an intimate connection of some kind subsisted between electricity and magnetism. The discovery of the real nature of this connection was made in 1820 by Professor Oersted of Copenhagen.

169. If a magnetic needle is held along the conducting wire of a voltaic circle in action, it is made to deviate: if it is suspended along and *above* the wire, it instantly turns about and hangs directly across it: if it is next hung along and *beneath* the wire, it will deviate and lie across, but the ends will be the reverse of the former case—the end that went to one side of the wire is now on the other side: if the needle is hung along the wire *at one side*, or in the same horizontal plane, it dips; one end falling beneath the level of the conducting wire, the other rising above it: if carried to the *other side* of the wire (without being reversed), it dips in the same way, but the pole that was down is now up. Thus it appears that a voltaic current has the power of acting on a needle; but that this power lies not in the direction of the wire, but *across it.* It is as if a magnetic power encompassed or circulated round the channel where electricity flows; or as if a particle, in receiving and transmitting the electrical

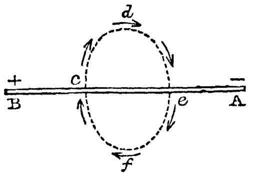
polarity, acquired also a pair of magnetic poles and a magnetic axis, lying directly across the electric axis. Thus let there be two adjoining particles of conducting wire, and suppose that the passage of the electricity lies through them, and that, in transmitting it, *a* is positive, *b* negative, and *c* positive, and *d* negative; then drawing a cross axis *pp'*, the points *p* and *p'* are magnetic poles; or rather if a cross circle were described, the whole circumference would be magnetic; a current of magnetic attraction would go round it, so long as a current of electrical polarities went along from one to the other. Thus while the line of chemical attraction lies one way, the line of magnetic attraction is transverse to it. In chemical decompositions, the separated elements pass in the direction of the current, the attractions and repulsions which it produces on them are in its own course; but the attractions and repulsions that it exerts on magnetic bars is across or around its course. Under this singular and unexpected condition an electric current is a magnetic force. The voltaic circuit is a revolving magnet.



170. We have stated that if a needle be hung along the side of a voltaic wire, and level with it, one end will be depressed and the other elevated. If the needle has its ends reversed, while it is kept on the same side of the wire, the same pole will be down, although pointing along the wire in the opposite direction. But if the voltaic current is reversed meanwhile, by fastening to the copper the end of the wire that came from the zinc, the dip of the needle is reversed, the raised pole is now depressed. So that the new magnetic force has a genuine polar character: a south pole circulates round the wire one way, and a north pole the opposite way, with the same current; but the reversing of the current makes a reversal of the magnetic circulation.

171. The connection between positive and negative currents, and north and south poles, is somewhat puzzling to remember. It must, in the first place, be borne in mind, that the north pole of a needle is that which points to the north pole of the earth: this designation, although erroneous, and against the laws of magnetic attraction, still continues to be used. Let AB be a portion of a conducting wire, A being the *negative* or zinc end, and B the *positive* or copper end. Then a current of positive electricity is flowing from A to B, or from right to left, and a current of negative electricity from left to right.

If now the needle is held along and above the wire, its north pole will go away from the observer in the direction of the arrow at *d:* if it is held below the wire, in taking its cross position the north pole will point to the observer in the direction of the arrow *f.* When held along the wire on the same level, and between it and the observer, the north pole is elevated, as is pointed out at *c;* on the other side of the wire, the north pole is depressed, as shown by the direction of the arrows at *e.* Thus while a positive current of electricity flows from right to left, the north pole of a needle is carried round in the direction that we would turn a handle with the right hand; and consequently a current of *south* magnetism flows in that direction. Or we may say that if a positive current passes before the breast from right to left, the head would represent the north pole of the attracted needle, and the feet the south pole.

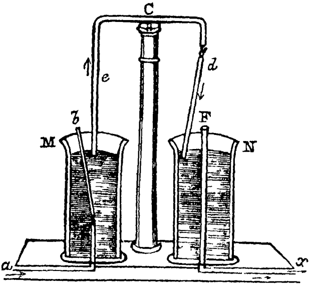


172. If the wire of an electric circuit is thus a magnet, it ought to show attractions and repulsions for other electric wires. This actually takes place. If the wires of two circuits are laid alongside of each other, and are free to move, they are mutually repelled if the direction of the current is the same in both, and attracted if the currents are contrary; so that without the mediation of a steel magnet, the forces circulating round the wires are able to show themselves.

173. Nothing but a *current* of electricity can produce magnetic power: the charge of a Leyden battery, however intense, has no effect. But during the discharge, which makes a current to flow, the magnetism may become apparent. For magnetic purposes the *intensity* of a current avails nothing, intensity being connected with stagnation or resistance; the effect depends solely on the *quantity*. Hence batteries made up of very large circles are used in electro-magnetism. Chemical and magnetic power are both in proportion to the quantity of the excitement, without regard to its tension, or that virtue whereby it could strike a blow or force its way through resistance.

174. An apparatus has been contrived to exhibit in action the revolving power of the magnetism of the electric current. It may be so arranged that a magnet shall revolve round a wire; or, on the other hand, that a wire shall revolve about a magnet. The figure represents the method of producing both effects. M is a glass cup containing mercury, through whose

bottom rises a wire from *a* the conductor of a circle. To the bottom of the cup is attached by a thread a magnetic rod *b*, which floats in the mercury, and is long enough to rise above the surface. Another wire, C *e d*, coming through the pillar C from the other end of the circle, dips into the mercury, and a metallic communication is thus formed between it and the wire entering at the bottom of the cup. A current of electricity now passes along the wires and through the mercury. The upper end of the magnet *b* is within the range of the force circulating around *d*, and, being free to move, it actually revolves about the wire so long as the current continues. By the arrangement in the other half of the figure, the wire revolves round the magnet. N is a glass cup of mercury, and F a magnet fixed to the bottom, and projecting above the surface. The wire from *x* enters the bottom of the cup and touches the mercury. The wire *d* is hung from a hook, and its end dips into the mercury, which forms a metallic or conducting connection between it and the bottom wire. The circuit being closed, the magnetic action commences; the current of force circulating around the wire encounters F the pole of the magnet; there is a mutual action, but F, being fixed, the movement takes place on the wire, which describes a circle in the mercury around F. Both actions may go on from one current, circulating along *a b e* C *d x*, and the revolutions will be in the same direction; for although the current that passes up one wire passes down the other, and reverses the magnetic circulation, this is exactly met by the magnet moving in one case and the wire in the other. If the same current passed up both wires, the revolutions in this arrangement would be opposite.



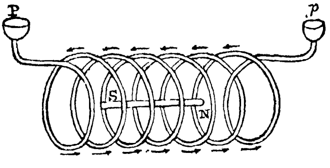
175. A magnet has been made to revolve about itself by passing an electrical current through it, to the middle, and no farther. If the current were passed from end to end, it would urge the one end to revolve one way and the other in an opposite way, and no effect would arise; but by confining it to one-half, the rotation is produced. This may be done by immersing it up to the middle in mercury, and passing electricity into it at the upper end. The current on descending

the bar to the surface of the mercury passes off there without entering the immersed half.

176. The electro-magnetic force acts upon soft unmagnetised iron on the same principle as the ordinary magnet. Indeed its power is best developed by being inductively communicated to soft iron bars, which are magnets so long as they are under its influence. An iron bar, made magnetic in this way by an electric current, becomes an electro-magnet, and by it we can produce every effect of the common magnet.

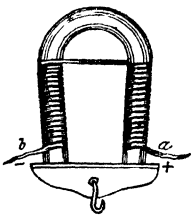
177. A needle of soft iron, laid across a conducting wire, lies in the wire's magnetic direction, and is magnetised by induction. But the action of a single straight wire upon an iron rod would be very feeble. If, however, we bend the wire round the rod, and coil it again and again, we increase the amount of the magnetic circles which act on the iron. Instead of an inch of wire communicating its influence, we may have the inductive force of many feet, and a very powerful magnetism will be imparted. It is by coiled wires, therefore, that electro-magnets are formed. A spiral coil is technically called a *helix*. Such a form possesses all the powers and properties of a magnetic bar when the electric current passes through it. It attracts and repels other magnets, communicates temporary magnetism to soft iron by induction, and permanently magnetises steel.

178. A striking effect of the attraction of a magnetic bar by a helix is shown in the figure, which represents a coil ending in two little cups P and *p*, where the communications are made with the poles of the battery; a small portion of mercury is poured into each cup, and the battery wires are dipped in the mercury, which thus forms a very perfect metallic junction. If a magnet S N is laid in the coil, and the circle completed, the action is such that the magnet starts up and suspends itself in air in the centre of the hollow, and hangs there so long as the electricity circulates. The opposing actions of the different ends and sides of the wire so neutralise each other, that it is not drawn either out or in, or nearer to one side than to another; and its only position of rest is a nearly central station: its own weight necessarily adds to the downward tendency, and keeps it a little below the axis of the spiral.



179. In communicating temporary magnetism to a soft iron bar, with the view of forming the electro-magnet, we

may choose either a straight bar or a horse-shoe: the latter is represented in the figure:—The wire *a* from one pole of the circuit, is coiled round and round the iron many times, and goes off at *b* to join the other pole. If the positive current pass in at *a*, *a* will be the north pole of the magnet, and *b* the south, according to the rule already laid down. To make a powerful magnet, the copper wire should be thick, and covered with silk, to prevent the electricity from passing sideways from one coil to another, or to the iron bar. A lifter is attached for the suspension of weights. An electro-magnet may be made of far greater power than an ordinary magnet of the same size. A horse-shoe, whose arms are eighteen inches long, and two inches thick, may be made to sustain 1000 lbs. if a strong current is passed through it.



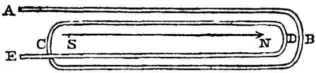
180. To determine which is the north and which the south pole of an electro-magnet, we can revert to the action already described of a straight wire on a needle. If a wire lies before us across our breast, and if a positive current passes from right to left, a needle's north pole is made to describe a right-handed circle—that is, the south pole of the wire's magnetism goes round in the circle in which the right hand would move a winch. If, therefore, a soft rod lies up and down on the other side of the wire from us, its lower end will be south and its upper end north, these being the poles of the wire's revolving action. If the wire is now coiled round it while it stands upright, the effect will continue the same, so long as positive electricity passes from right to left along the coil between our breast and the bar. Suppose we clasp our arms round a tree, and that a positive current circulates from the right hand along the right arm across the breast to the left; in this case the top of the tree would represent the north pole and the root the south.

181. If a steel needle or bar is laid in the inside of a helix, and a strong current passed along, it will acquire a permanent magnetism. The helix which answers best for this purpose is a short thick coil, formed by first winding the wire into one spiral, and then laying upon it a second layer, and then a third, and so on till a great thickness is reached. A powerful current is sent through it, and the bar inserted and moved once forward its whole length, then backward till its middle is in the centre of the coil; the current is then stopped, and the bar taken out perfectly magnetised.

182. Thus the electro-magnetic power is in all respects

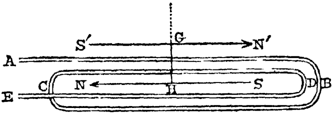
identical with the loadstone and the earth's magnetism; only it can be raised to a much higher degree of intensity than ordinary magnetism. By using a strong battery of Grove's construction, a mechanical force can be developed which is perfectly enormous. There is scarcely any limit to the power which may thus be created. The wire in contact with the iron may, by successive coilings layer above layer, be extended to hundreds of feet; and if the battery is powerful enough to send the current through the entire length, the magnetism is increased in proportion to the quantity of the wire accumulated round it.

183. The electro-magnetic action has been applied to form an electrometer of a very delicate kind, which is essential in experimenting with voltaic currents and electricity of weak tension. It is the proper voltaic electrometer or *galvanometer*. If a magnetic needle S N is suspended within several bendings of conducting wire A B C D E, and hung parallel with the wires, the setting on of the current will make it deviate and lie across; it will thus be a visible mark of the passage of electricity. It will be turned aside by nearly four times the force that would be exerted by a single wire; hence the apparatus has been called a *multiplier*. But instead of two circles of coil, fifty or a hundred may be made, forming a helix with an oval section, and within this the needle is hung. When the instrument is used, it is placed so that the direction of the helix is in the magnetic meridian; hence the needle will, under the earth's attraction alone, lie exactly alongside of the wires. When the current is set on, a deviation will take place; but the needle will not be carried so far as to lie directly across, unless the current be as strong as completely to overcome its polarity to the earth, and its own inertia and the resistance of the suspension. With a weak current, the deviation may be very trifling, but as the current increases in strength, it becomes greater; hence the angle described is a measure of the power of the charge sent through the wire.



184. An improvement has been made upon the instrument, which gets rid of the action of the earth's magnetism, and consequently leaves the needle more free to move aside under the influence of the electrified helix. Instead of one needle hanging within, two needles are used, one within and the other above the oval coil; the upper one having its poles lying reverse to the lower, as in the figure. N S is the inner needle, S′ N′ the outer; being on different sides of the set of wires,

they would deviate in opposite ways if their poles were in the same direction; but the reversal of the poles causes different sides of the current to move them both in one direction. The two may therefore be fixed on one axis of suspension, and they will act under the influence of current as a single needle. But the earth's magnetism will of course affect each of them: since, however, they lie in opposite directions, it will tend to draw N′ one way, and S′, which is on the same end, the other way; and the two attractions will neutralise each other, so that no movement will arise from the operation of the earth's magnetism, if the needles have exactly the same degree of polarity. It is unnecessary with this instrument to attend to a meridian position; and the deviation will be much greater from any given current than with the single needle; consequently the indications will be more delicate. By this instrument very feeble currents can be made apparent.



185. For measuring the force of powerful currents, it is not necessary to coil the wire or to use a silk thread for suspending the needle. A single coil placed in the magnetic meridian, and enclosing a needle on a point, will serve to measure the strength of such currents. The stronger the current, the more will it overpower the tendency of the needle to point to the north, and hence the angle of deviation from the direction of the coil or the magnetic meridian will correspond to the strength of the circulating electricity.

ELECTRO-MAGNETIC MACHINES.

186. Many important practical applications have been made of the voltaic magnetism. Of these the most prominent is the Electrical Telegraph, invented by Professor Wheatstone, and perfected by him and others, and now in extensive operation over the lines of railways.

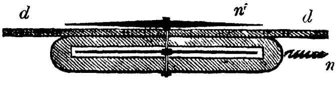
187. The electrical telegraph depends on the power of an electric current to cause the deviation of a magnetic needle, and on the great distance that the power may be conveyed. In the experiments of Mr Wheatstone, it appeared that a current could be transmitted through four hundred miles of wire without being extinguished; so that at the end of that distance it could cause a sensible magnetic action.

188. The apparatus of the telegraph consists, in the first

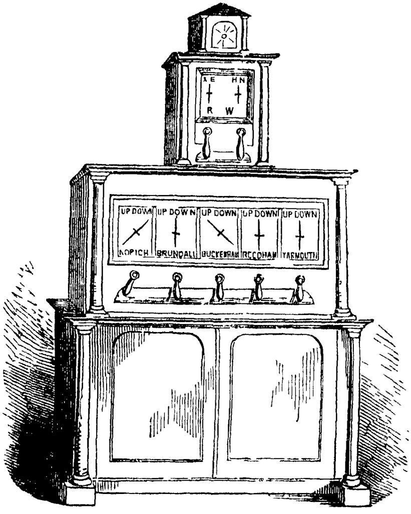
place, of a line of conducting wire suspended on poles, and reaching from station to station. On the first introduction of the telegraph, a pair of parallel wires was thought necessary, in order to complete the voltaic circle; but it is now found that the earth can make the returning part of the circuit, and that it may therefore be formed by means of a single wire. At each end, the wire is carried down to the ground, and attached to a large plate of metal buried there; and the current finds its way through the earth from one of the metallic masses to the other. The wire is formed of iron coated with zinc by a particular process, and receives the name of galvanised iron wire: it rests on the poles in earthenware tubes, in order to insulate the passing electricity.

189. The second essential of the telegraph is the *battery*. The kind of battery which seems to answer best is the partitioned trough, with a pair of copper and zinc plates in each cell. The cells are filled with dry sand, which is moistened with dilute sulphuric acid when it is to be set in action. This arrangement is found to yield a very constant and enduring voltaic current. The greater the distance between the stations, or the longer the circuit, the more powerful of course must the battery be. The resistance to the current necessarily increases with the length of the wire, and at a certain distance it would be too feeble to produce a deviation of the needle, or any other palpable movement.

190. The third necessary part of the telegraph circuit is the *needles*. These are the indicators of the excitement, and the instruments with which the signs are made. In order that the current may deflect a needle forcibly, an oval coil is formed on the principle of the galvanometer; and two needles are used, one within the coil and one without, as in the figure, which gives a side view of the instrument, *n* being the inner needle, and *n′* the outer. As in the galvanometer, the needles are arranged with their opposite poles together, so that the earth's magnetic action upon them is neutralised; and from their being on different sides of the coil, they are both moved in one way by the same current. *n′* is the needle that is visible, and it lies upon a dial-plate *d d*, seen edgeways in the figure. The helix or coil makes part of the great circle; and when the battery is in operation, and the circuit closed, the needle is moved across the coil, or deflects from the upright position which it occupies when unexcited. If several needles are mounted on one circuit, all will be moved in the same way at the same instant.



191. The fourth essential part of the machinery is an apparatus for making and breaking the metallic contact, or closing and opening the circuit, and also for reversing the current, so as to give an opposite deflection of the needle, and thus vary the signal. This has been executed in several ways. The external instrument is a handle that may be swayed to the right or left, according to the deflection to be given to the needle. The accompanying cut represents the Norwich Railway apparatus, with its needles and handles; a separate wire and circuit being necessary for each needle. So few as two needles have, however, been found sufficient to make all the requisite communications. The needle to the left is seen deflected one way, and that in the middle the opposite way. An agreement must be made as to the meanings represented by each deflection or combination of deflections. Thus in a double needle apparatus, each letter of the alphabet and each arbitrary sign must have a different aspect; and yet there are only four simple movements which can be made—namely, a right and left deviation of each needle; the combinations of these movements would give in all twelve distinct configurations of the needles. But by repeating the vibrations, any number of different signals may be made—that is, each needle may be deflected once, twice, or thrice for the same signal; a pause being allowed after the signal is completed, to distinguish between the successive deflections of one sign and the transition to another. At the end of a word a particular sign is made to show that it has been completed. It is found possible to communicate at the rate of fifty letters a minute.



192. The apparatus for signalling may be very various, and many schemes have been proposed with the view of quickening the process of communication. Bain's new system consists of causing the electric circuit to make coloured spots in a piece of paper soaked with sulphuric acid and prussiate of potash; employing the chemical instead of the mechanical action of the voltaic circle to make the indications. The moistened paper is wound in a metallic roller, which is kept moving while the end of a metallic spring rests upon it; the apparatus forming part of the great telegraph circle. While the circle is broken, no effect is produced; but when it is closed, the current passing through the wet paper effects a decomposition that shows itself in a blue spot. At the other end of the line an apparatus of a similar kind is placed; but the strip of paper is dry, and acts as an insulator. It has holes punched in it, which, in the course of the movement, come under the spring, and allow it to touch the naked roller, and make a perfect metallic contact, and thereby close the circle. At the instant, therefore, a hole passes beneath the spring at one end, a coloured spot appears beneath the spring in the apparatus at the other end; so that the series of holes are exactly represented in a series of blue spots. If, therefore, aggregations of holes are chosen to represent letters and signs, these can be faithfully repeated and read; and the apparatus can be driven with far greater rapidity than the needle system.

193. Although the telegraph is by far the greatest application of voltaic electricity and electro-magnetism, it is not the only application. Much ingenuity has been spent in contriving machines for bringing electricity into play as a prime mover, like wind, water, steam, or gunpowder. The mechanical force of an electro-magnet, as we have seen, is very great; and there seems no reason why it should not be used as a source of power in moving machinery. Whether it would be as cheap or cheaper than steam-power, must depend on many considerations. But at all events it might be found preferable to other prime movers in special cases and circumstances. As yet, however, no effective method has been contrived for bringing the power to bear upon machinery. It has the peculiar character of being a very intense force acting through short distances; and it is requisite that this mode of action should be converted into a rotatory motion, in order to be generally applicable to movements. An apparatus has to be formed which will do the same for the magnetic attraction that Watt contrived for the expansive force of steam, when he joined together a cylinder and piston, parallel

motion, cross beam and crank, to convert the reciprocating steam-pressure into a wheel movement. The magnetic force is also a reciprocating force, but of very short range and varying power; and some suitable apparatus must be interposed to transmit its whole amount to the steady whirl of a shaft or axis. The machines hitherto contrived have not been able to communicate the whole power of the magnets to the rotatory apparatus, and they are therefore no fair criterion of the mechanical force which may be obtained from the consumption of zinc and acids in a voltaic circle.

194. Mr Bain has succeeded in applying electricity to move the pendulums and machinery of clocks. For the ball of the pendulum he makes a hollow coil of copper wire, whose opening or axis looks right and left, or in the direction which the pendulum swings. Two magnets are fixed so as to point into the opposite ends of the coil, and face each other. If a current of electricity is sent through the coil, it becomes an electro-magnet, and is attracted to the nearest magnet. Accordingly, means are provided for communicating at every vibration a current to the pendulum, and for cutting it off while it passes the middle line, and recommunicating it at the other end of the sweep. A plate of zinc and a plate of copper are buried, facing each other, in the earth at a depth of at least nine feet, that there may be a constant supply of moisture. The damp earth is thus the exciting element of the circle, which has a permanent action. Wires are carried from the plates, and passed along the pendulum, to connect with the coil which forms its ball. About the middle of the pendulum rod, an arrangement is made whereby the motion of the pendulum closes, breaks, and recloses the current according to the place where it lies in its vibration. The attraction of the magnets is thus made to sustain its motion and the motion of the connected wheelwork. It may be regulated to beat exact seconds like an ordinary pendulum.

MAGNETO-ELECTRICITY.

195. Magneto-electricity is the counterpart of electro-magnetism: the one explains the production of magnetism by an electric current; the other shows how an electric current may be produced from a magnet. This branch of the science was created by Professor Faraday.

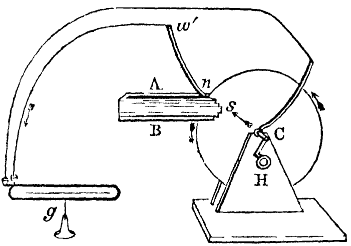
196. If an electric current and the magnetism of a bar are so closely allied that the first can give rise to the second, it was natural to expect that the second should be able to cause the first; or that a magnet might be so placed with reference to a conducting wire, as to produce in it a current of electricity. The experiment may be tried in many ways. Thus since a helix charged with a current can magnetise a bar lying in it, let us take a bar magnet and put it into a coil which has no connection with a voltaic circuit, but whose ends terminate in a galvanometer, and which forms a complete circle of conducting wire. We have now an active magnet lying in an unactive helix; but no current is observed. Although the active magnet is in the very place where an unactive bar would be magnetised by an active wire, yet the circumstances being reversed, the active magnet cannot induce magnetic currents around the wire, so as to make electric currents run along it. Let us, however, seize hold of the magnet, and instead of its lying at rest in the hollow of the coil, let it be moved backwards or forwards; a current is immediately observed, the needle of the electrometer being sensibly deflected. While we continue to move the magnet in or out, the current is maintained; when we let it rest, the current ceases: so that an active magnet has the power of creating electric currents, if it is moved in the direction of its length across a wire or assemblage of wires. The motion of the bar is essential to the effect. The necessity of motion is owing to the character of the magnetism of a conducting wire; for this magnetism is not a reposing or statical magnetism, but a current or revolving magnetism; and unless the statical magnet is itself set in motion, it cannot be the cause of a current magnetism. The electricity arising from this action is called Magneto-Electricity.

197. If an active wire, in connection with a circuit, lies alongside of another wire that is inactive and connected with a galvanometer, the current of the first has no influence in making a current in the second while both wires are at rest; but at the instant the current is arrested, and the instant

that it is set on upon the first wire, a momentary current appears on the second. While the current continues, there is no action. Let, however, the wires be made to approach each other, and a current ensues on the inactive wire; when the wires are at a stand still it ceases. Or if they are drawn away from each other, a current in like manner arises, but opposite to the current during the approach: so that there are two methods of passing a current from an active to an inactive circle. We may either close or break the active circle, and thereby create an instantaneous current; or we may move the wires nearer or farther from each other, and during either motion we have a current on the inactive circle; the approach making it in one direction, the recession making it in the opposite direction. These effects are designated by the term Volta-Electric-Induction; and the currents Induction Currents.

198. The approximation or separation of the wires is exactly similar to the moving of the magnet in the coil, or across a wire. An active wire is a magnet, and if it is moved sideways towards another wire, the effect is the same as if a magnetic bar were moved endways. The side motion of the one can do exactly what the longitudinal motion of the other can do. In both cases mere proximity has no effect; but, by movement, each can excite a current in a dead circle.

199. Faraday was able to produce a permanent electric current from a horse-shoe magnet by the following apparatus:—A circular plate of copper C is made to revolve upright on a stand, and a handle H is fixed on the axis. Two conducting wires *w* and *w′* are connected at one extremity with the galvanometer *g*, by being plunged in its mercury cups. At their other extremities one of them, *w*, is connected with the axis of the copper plate; the other, *w′*, is made to touch its edge between *n* and *s*, the poles of the magnet A B, placed as represented in the figure. The plate is whirled by means of the handle, and a current of electricity is found to circulate round the wires; the nature of the current is reversed when the motion is reversed. The inductive effect being the same whether a magnet is moved along a conductor or a conductor along a magnet, the action is produced here by the copper edge constantly running across



the direction of the iron. A current thus arises on the edge and passes inward to the axis, and thence along the wire *w* to the electrometer, the opposite current taking the contrary course. When the handle is revolved from right to left, the positive current in the above apparatus has the direction of the arrows. The end of a bar magnet, held near the edge of the revolving copper, has the same effect as the horse-shoe.

200. The identity of electricity and magnetism was still farther confirmed when Faraday discovered that a spark could be drawn from the magnet. At the moment of making or breaking the magnetic contact, or when the lifter either completes the connection or breaks it, a spark is sent forth at the junction; or if the lifter is surrounded with a helix, the spark may be seen in the circle, by having at one part of it two surfaces very near, but not in contact—as a fine point almost touching a surface of mercury. The instant the lifter strikes the ends of the horse-shoe, or the instant it is drawn away, a spark passes through the open interval of the circuit.

201. An induced current, either from a magnet or from an active circle, produces a sensible shock, of the voltaic character, but more severe. Its intensity is higher than the intensity of the original current. When the induction is of the temporary kind which accompanies the opening and closing of the active circle, the shock is instantaneous; but by keeping up a constant induced current by movement, a continuous shock of a very painful kind may be communicated. Machines have been constructed for producing the permanent induction, called Magneto-Electric Machines; and in causing physiological effects, or for acting on the human body, they are the most efficacious of all electrical machines. Their principle is different from the revolving apparatus of Faraday above described. They are contrived so that a lifter may repeatedly make and break its contact with the magnet, and thus induce a succession of currents upon a circle of wire coiled many times round it. The lifter is made as if for an electro-magnet—in other words, it is wrapped round with a great many turns of wire; but the coiling is made so that the ends of the magnet point as it were into the hollow of the coil—that is, the lifter is not simply a cross bar, but has across its ends two cylinders, facing the ends of the horse-shoe, and receiving the wire coils. If the magnet is now rapidly revolved on an axis running between its legs, the constant movement of approach and retreat from the coiled lifter maintains a series of currents, and these are twice reversed at each revolution; for one kind of current arises when one pole approaches one end of the lifter, and an opposite when this pole leaves it and the

other pole approaches. This incessant reversal of the current is probably the cause of the very painful character of such currents when transmitted through the arms. The wires of the coil terminate in small copper cylinders, which are held one in each hand; and if the hands are previously moistened with salt water, the shock will be experienced to the fullest advantage. The more rapidly the magnet is whirled, the more intense will be the action.

202. The machines first constructed made the magnet to revolve as above described; but subsequently they were formed so as to make the coiled lifter revolve, while the magnet remained fixed. The apparatus is so arranged that the shock passes upon the circle through the body only when the keeper faces the ends of the magnet; when the keeper leaves the poles, the connection is broken, and remains broken till half a revolution takes place, when the opposite current is induced as a shock, and instantly stopped. Thus there is given a succession of disjoined and contradictory shocks.

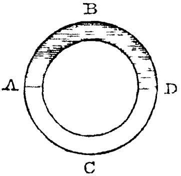
203. Chemical decomposition has been effected by magneto-electricity; but as this demands a copious quantity of the current, it requires large magnets to make it apparent. The machines are generally compound horse-shoe magnets of large dimensions. The wire coiled on the cylindrical branches of the keeper is very long, sometimes many hundred yards. For chemical decomposition an arrangement is adopted, called the *quantity* arrangement, for securing a continuous current in the same direction, as no decomposition arises when the electricity is continually interrupted and reversed; the one polarity must necessarily counteract the other. Hence the machines which give the most violent shocks are sometimes totally inefficacious in decomposing compounds.

204. As the earth is a magnet, it ought to have the same power as other magnets to induce electric currents. Faraday succeeded in proving this to be the case, by making the same arrangements as were necessary for a portable bar. A conducting circle is made to revolve across the direction of the earth's magnetic pole, or at right angles to the dipping needle, and in this way it acquires an electric current, which can be distinctly made evident by the galvanometer. Hence Faraday inferred that voltaic currents must be frequently generated by the accidental movements which take place on the earth. Thus in high north latitudes, where the pole lies almost vertically down, a wheel revolving horizontally would be moving across the magnetic direction, and would have a current induced upon it. So even running water in the polar regions would experience voltaic excitement from the earth's magnetism.

THERMO-ELECTRICITY.

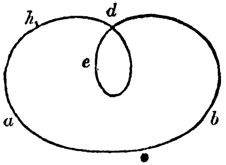
205. It has been seen that an electric current, passing through an inferior conductor, or in anyway interrupted without being completely checked, gives forth heat. Resistance to its passage is the means of converting the polar excitement into an increased temperature of the resisting material. On this condition heat and electricity are reciprocal. But although it has always been very easy to produce heat by an electric current, it was only in 1832 that the means were found of producing an electric current by heat. This discovery, made by Professor Seebeck of Berlin, gave rise to the science of Thermo-Electricity, which completed the evidence of the reciprocity of the electrical and the other effects. Volta had produced the excitement by chemical action, Professor Faraday from the magnet, and now it is derived from heat; its three greatest effects are thus found to be in turn its causes.

206. When two metals whose susceptibility to heat is unequal are soldered together, and heated at the joining, an electric current is evolved. Thus if A B C D be a metallic circle, the one half, A B C, being *bismuth*, the other half *copper*, and if a lamp be applied at A, one of the joinings, it will heat both metals, and cause electric currents to flow round the circle. A positive current will pass from the bismuth to the copper, or round in the direction A B C D, the negative taking the opposite course. Thus when two substances, differently disposed in regard to the reception of heat, are heated together at their point of contact, the discrepancy shows itself in the two metals polarising each other, and yielding electricity.



207. If we heat a wire which makes part of a circle attached to the galvanometer, the heat will be conducted off right and left along the wire, at an equal rate, and no electricity will arise. But if in anyway we cause the heat to pass round more copiously to one side than to the other, a current will be made apparent. Thus if we make a loop upon the wire, and make it touch at the crossing, this will retard the passage of the heat to the side where the loop is, and thereby disengage electricity or polarise the wire. Thus suppose the heat

applied at *h;* it will be conducted along the wire each way; but at the loop *d*, part will go along *d b*, the proper direction, and part will be communicated to *d e*, which will make it return again towards *h*, and, on the whole, impede the conduction on the way to *b*. So that the heat will travel at a greater rate round by *a* than round by *b;* and it would appear that when unequal currents of heat encounter, they issue, not in a simple increase of one another, but in a polar effect, or they make an active voltaic circuit. On the same principle, if one end of the wire is oxidised, it will be made a worse conductor, and electricity will be manifested. A crystallised body may sometimes produce a current on the application of heat, owing to the fact, that the heat passes more easily through one side than through another in some crystals.



208. It is found that when hot water mixes with cold water, electricity is produced; the hot liquor being negative and the cold positive. Other liquids show a similar action; but the kinds of excitement are not invariable: a hot acid mixed with a cold acid makes the first positive and the second negative. Hence it appears that the passage of heat must in general cause electrical polarity; only if two equal portions of heat pass round in a circle and meet, they will neutralise each other's effects, and no excitement will be apparent.

209. If, instead of bismuth and copper, bismuth and antimony are soldered together, the effect will be greater, the disparity of the metals being greater. This last couple is what is usually adopted for a thermo-electric circle, being superior to any other that could be chosen. The following table exhibits the order of the principal metals in regard to thermo-electric combinations:—

Bismuth	Platinum	Copper	Zinc
Mercury	Lead	Silver	Iron
Nickel	Tin	Gold	Antimony.

The farther asunder two metals are in this table, the more powerful is the couple formed by them. Bismuth and iron would make the next best couple to bismuth and antimony. Silver, gold, and zinc are very nearly equal in the effects which they would cause, if coupled with a metal from the other end of the table. Each metal causes a positive current to pass upon any metal beneath it, and a negative upon any metal above it. Thus if platinum and copper were soldered together, a positive current would pass from the platinum to the copper, and the negative from the copper to the platinum; or the actual state of each would be—platinum negative, copper positive; that is to say, if two plates were laid on each other, and heated at the joining, the free side of the platinum would be negative, and the free side of the copper positive. Positive electricity radiates from the joining through the copper mass, negative electricity through the platinum mass.

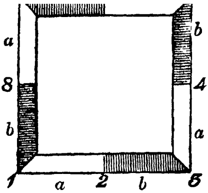
210. Various mineral substances may enter into the thermo-electric circle, such as plumbago, peroxide of manganese, per-sulphuret of iron, and galena. Plumbago is positive to platinum, and stands pretty near the lower end of the table. The per-sulphurets stand near to bismuth.

211. The order of the metals above given does not correspond with their goodness as conductors of heat. Bismuth, indeed, and the metals near it, are the worst conductors of heat; while some of the metals near the other end, such as gold, silver, and copper, are among the best conductors. But there are very decided exceptions. Platinum ranks with gold and silver in conducting power, but it is far removed from them in the thermo-electric series. Iron is inferior as a conductor to all of these, and yet it is nearer the antimony than any of them. It cannot, therefore, be laid down as a rule that the worst conductors of heat rank highest in the thermo-electric series, or that a good and a bad conductor will make an effective couple.

212. But if we classify metals according to their power of radiating heat, or of receiving it by radiation, we find a near coincidence with the above order. A metal does not radiate heat from its surface in the same proportion that it passes it through its substance; the proportion is more nearly an inverse proportion. The worst radiators are at the top of the table, and the best radiators at the bottom. Hence it appears that when heat is applied to the joining of two metals, and when the one is slow at receiving the imparted heat, while the other receives it abundantly, the inequality thence arising is the cause of the electricity. For the heat applied to the couple being that from a lamp or a fire, it is communicated by radiation; and as bodies which radiate well, receive radiant heat equally well, the best radiator will be most heated, and will be negative, and the other positive; so that in general the side of the joining where most heat is received is the negative side, and through it the negative current passes to the wire of the circuit.

213. A single circle, made of a bar of bismuth and one of

antimony, soldered together, makes a simple circuit or couple; but any number of bars may be laid together, so as to make a compound thermo-electric circuit. If they are joined one to the other in a long line, or in a circle, the heat will have to be applied to every second joining. If the first, third, fifth, and seventh joinings are heated, while the second, fourth, sixth, and eighth are cooled, by being laid in ice, the force of the current will be increased. Cold has the same power of exciting electricity as heat, only the current is reversed. The figure represents a compound circuit of four bars of bismuth *b*, alternating with four bars of antimony *a*. Heat would have to be communicated either to the four corners or to the middles of the four sides. If the corners were heated and the middles iced, the effect would be thereby increased.



214. A series of bars of alternate bismuth and antimony may be, as it were, folded together in a bundle, the first, third, fifth, seventh, &c. joinings being at one end, and the second, fourth, &c. at the other end; the bars being kept from touching at their sides by an insulating substance. The last rod of bismuth is connected with a wire, and forms the negative pole; and the wire attached to the last rod of antimony at the other end will be the positive pole. The two ends of the bundle are blackened to increase their absorption. If either face is heated, a current will arise; if one is heated and the other cooled, the current will be greater; if both are heated alike, there will be no current.

215. Such a bundle of bismuth and antimony needles has been constructed to serve as a thermometer for delicate experiments on heat. Differences of temperature that are imperceptible by the mercury or alcohol thermometer, are found to affect the galvanometer of a thermo-electric pile. Radiant heat especially can be detected with extraordinary accuracy by exposing one end of the bundle to the heating rays.

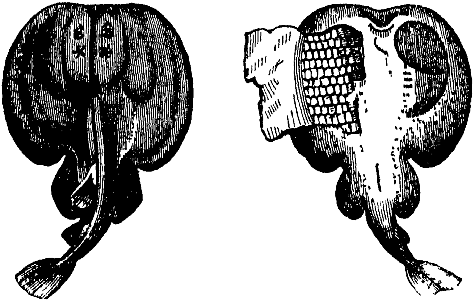
216. The current circulating in the thermo-electric circle is of weak intensity compared even with the voltaic pile, and therefore it is not adapted for giving shocks. But the quantity which it yields may be very great, and it is capable of decomposing chemical compounds. Also, by using a bundle of thirty elements or pairs about an inch thick, and heating one end by a hot iron placed near, and cooling the other with ice, the intensity of the current is sufficient to make a distinct *spark* in daylight, when the circle is broken or closed.

217. The discovery of thermo-electricity suggests an explanation of the probable origin of the earth's magnetism. The sun's rays heating the earth in one place after another in his daily circle, would cause an electric current to circulate round the globe in an equatorial direction, or more strictly, in the direction of his path. If we suppose him for a moment standing over any one place, it is obvious that the portion of the earth to the east of that place is hotter than the westerly portion; because what he has been recently shining on must be warmer than the ground he is only approaching to shine on after a day's absence. But we have seen that, in the thermo-electric circuit, negative electricity flows from the joining to the hot side, and positive electricity to the cold side; therefore the motion of the sun from east to west will cause a positive current to move in the same direction, and a negative current from west to east. But if we refer to the rule for determining what would be the magnetic polarity of the earth arising from such a current according to the laws of electro-magnetism, we find that it would give to each hemisphere the same kind of polarity as they actually have. If the daily path of the sun were from west to east, the earth's magnetism would be the reverse of what it is: so that the sun's heat circulating round the globe will necessarily magnetise the earth. The daily and yearly fluctuations of the needle also tend to show the connection of terrestrial magnetism with the sun's motions. It may therefore be said that the sun is the great source of all power on the earth. It gives warmth, supports vegetation, draws up the water to the clouds, originates the thunder and lightning, and produces magnetism and all its consequences. The earth's own forces of gravitation and cohesion, and its attractions in general, tend to aggregate, solidify, and condense the whole of its substance into a compact heap of lifeless matter; the sun supplies the counteractives of these, and causes expansion, separation, decomposition, and all the agencies which lead to the renewal of movement and life.

ANIMAL ELECTRICITY.

218. This branch of the science refers to the production of electricity by living bodies, and gives an account of certain animals that possess within their structure special organs for generating electric currents; it may also include what is known of the effects of electricity on the animal system. The former subject would be named Animalo-Electricity, if we followed the analogy of the preceding names—Magneto-Electricity, Thermo-Electricity.

219. There is a flat fish found on the shores of the Mediterranean, and on the Atlantic coast of France, which has been known from antiquity to give benumbing shocks to any one who handles it. It is called the *Torpedo*. When dissected, there are found in it two organs, or masses of honeycomb structure (see fig.), one on each side of the body at its broadest part, or near the head. In an animal 18 inches long, 12 broad, and 2 thick, each organ is about 5 inches long; the breadth is 3 inches at the head, and at the other end half an inch; being, as it were, triangular, the narrow end pointing to the tail. They occupy the whole thickness of the fish from breast to back, as far as they extend; they consist of a mass of roundish columns, whose direction is from breast to back, or upright when the fish lies flat. Each of these columns seems to be made up of a succession of distinguishable layers piled upon one another, and separated by mucous partitions; hence it has been supposed that the electricity is produced in the same manner as in the pile of Volta, or that the entire organ is an immense bundle of piles lying side by side, conspiring altogether to make an electric charge. The number of columns in each



organ depends on the size of the fish; in the one whose dimensions are stated above, 470 were counted in each; but as many as 1182 have been seen in a very large specimen. The number of layers or distinguishable partitions in a column an inch long has been found to amount to 150. A very large supply of nerves is afforded to the organs; they ramify into each column, and are distributed to the partitions—every partition receiving a nervous filament.

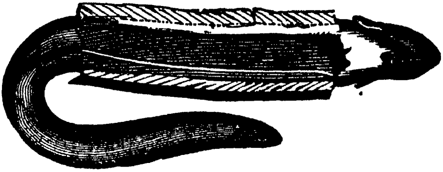
220. The back of the animal is positive, and the breast or belly negative, and the currents pass through the body between the breast and back. On touching either side, a shock is received; but by seizing the animal, and holding it by both sides, a much more intense shock is felt. In a second or two after receiving one shock, the charge accumulates, and discharges itself again, and thus a succession of shocks may be given, until the strength of the animal is exhausted. The electricity has to the feeling the same character as a discharge of very small Leyden jars; the intensity is small compared with machine charges, but equal to that of a very numerous voltaic pile. It is capable of magnetising iron, and of decomposing compounds; but its quantity being small, these effects are not produced to any great extent. Its use to the animal seems for defence against attacks, and as an offensive weapon generally; instead of devouring and destroying by the teeth, it launches its diminutive thunderbolts upon all creatures that approach it.

221. A second animal endowed with electrical organs is that called the *Gymnotus Electricus*, or electrical eel, found in various parts of America It was seen in great numbers by Humboldt in the swamps of the Orinoco in South America. Its common length is about five feet, but it often occurs much larger. Its shocks are far more formidable than the discharges of the torpedo; men, and even horses, going into the water are stunned by its touch, and are frequently drowned before they have time to recover. The following description by Humboldt of the method adopted by the Indians for catching the gymnoti, completely illustrates their character and habits. They bring a troop of wild horses, and cause them to enter a muddy pool where they are contained. "The extraordinary noise caused by the horses' hoofs makes the fish issue from the mud, and excites them to combat. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organisation, furnishes a very striking spectacle. The Indians, provided with harpoons and long slender reeds, surround the

pool closely; and some climb upon the trees, the branches of which extend horizontally over the surface of the water. By their wild cries, and the length of their reeds, they prevent the horses from running away, and reaching the banks of the pool. The eels, stunned by the noise, defend themselves by the repeated discharge of their electrical batteries. During a long time they seem to prove victorious. Several horses sink beneath the violence of the invisible strokes which they receive from all sides on organs the most essential to life, and, stunned by the force and frequency of the shocks, disappear under the water. Others, panting, with mane erect, and haggard eyes expressing anguish, raise themselves, and endeavour to flee from the storm by which they are overtaken. They are driven back by the Indians into the middle of the water; but a small number succeed in eluding the active vigilance of the fishermen. These regain the shore, stumbling at every step, and stretch themselves on the sand, exhausted with fatigue, and their limbs benumbed by the electric shocks of the gymnoti. In less than five minutes two horses were drowned. The eel being about five feet long, and pressing itself against the belly of the horses, makes a discharge along the whole extent of its electrical organ. The horses are drowned, from the impossibility of rising amid the prolonged struggle between the other horses and the eels. By degrees the impetuosity of this unequal combat diminished, and the wearied gymnoti dispersed. They require a long rest and abundant nourishment to repair what they have lost of galvanic force. The mules and horses appear less frightened; their manes are no longer bristled, and their eyes express less dread. The gymnoti approach timidly the edge of the marsh, where they are taken by means of small harpoons fastened to long cords. When the cords are very dry, the Indians feel no shock in raising the fish into the air. In a few minutes our party obtained five large eels, the greater number of which were but slightly wounded."

222. In the gymnotus the structure of the electrical organ is not the same as in the torpedo. It occupies nearly four-fifths of the length of the animal, and is formed of thin plates lying in the direction of its length (see fig.); so that one end of the pile is at the tail and the other end near the head. Hence its shocks are most powerful when it brings both head and tail into contact with another animal. There are two pairs of organs, and their total bulk amounts to about one-third of the whole body of the fish. Two rows of small yellow spots are seen running along the back from head to tail, and every spot contains an opening which gives forth a mucous matter, which

covers the skin, and is found to be a remarkably good conductor of electricity.



223. In the rivers of Africa—in the Senegal, the Niger, and the Nile—is found a third species of electrical fish, called the *Silurus Electricus.* It is about twenty inches long. It is caught and eaten by the Egyptians. Its electrical organs lie beneath the skin all round the animal, and are less complicated than in the torpedo and gymnotus. Various other electrical fishes have been met with.

224. In all these animals the electrical apparatus is an addition to the ordinary vital organs, and its action is quite independent of them. It is not involved in the operations of digestion, circulation, or movement; but, like all other organs, it is supplied with nerves from the brain. It seems to be under the control of the animal to about the same degree as its moving apparatus. Although the structure of the organ is somewhat similar to a voltaic arrangement, and the shock the same as would be felt from a battery made up of several hundreds of small plates in a weak solution, it is not completely proved that it operates on the principle of the pile.

225. Apart from the possession of special apparatus, the operations of the animal body are such as to evolve electricity in many ways. The chemical processes of digestion and respiration—the constant passage of heat to and fro—the mechanical movements—may all generate electricity. The most common case of the appearance of excitement in the human subject, is when the clothes are stripped from the skin in a very dry air. When silk stockings are taken off, they sometimes cause a crackling noise, accompanied with sparks, which may be distinctly seen in the dark. If the skin and clothes are perfectly dry, this effect would probably be constant, as it is a mere effect of the friction. In very dry climates, where the atmosphere is so deficient in moisture as to keep all surfaces in a dry state, the observation is very familiar; it is also observed in rooms heated by stoves, which have the same excessive desiccating tendency.

226. Of the entire amount of electricity produced by the interior processes of the human body, only a small portion can appear in a free state on the surface; the greater part must be consumed again or discharged in other operations. In as far as the skin acquires a charge, its general character is found to be positive; but the amount differs very much in different individuals, and in the same individual at different times. A development of positive electricity seems to be identified with the health, vigour, and freshness of the body; for it diminishes, and is changed into negative, by great exertions and fatigue, by lassitude and cold. A sudden fit of violent exertion will in an instant convert the positive charge into a negative one. We may therefore suppose that the operations of nutrition are constantly generating positive electricity, while exertion and the wasting operations generate negative; that the nourishing processes are like the cells of the voltaic pile, where, by the consumption and chemical transformation of material, the excitement is produced; and the wasting operations like the place of action in the circuit, where the excitement is expended in producing effects of heat, decomposition, or moving power. Liebig has found that the juices of the flesh or muscle are constantly acid, while the blood in the arteries and veins circulating through the flesh is alkaline. But an acid and alkali, with a membrane between them, are capable of causing a current, the acid being positive, and the alkali negative; so that the blood would from this cause have a negative charge, and the flesh a positive charge.

227. The effects of electricity on the animal system are as yet very little understood. Electric shocks have been applied as remedies for diseases, and have often been productive of good. The chief disorder where they are found valuable is the case of paralysed limbs. By passing a long-continued series of discharges through a torpid arm or leg, it has often been restored to vigour. For this purpose the ordinary friction machine has been commonly employed; but it is supposed that the magneto-electric machine may prove a much more powerful stimulant. Relief has been given also to patients suffering from tic.

228. It may be surmised, that if the human body in its ordinary healthy state contains a surplus of positive electricity, and if the earth is in general negative, there is a propriety in keeping some insulating substance between the feet and the naked ground. We may thus assign an additional reason for the disagreeable and unhealthy effects of damp feet; for besides cooling down the system, the moisture will

conduct away the body's free electricity to the earth, and with this a certain portion of the vigour of the frame. On the same principle fogs, which are commonly negative, by enveloping the person, must take away its positive electricity; and their unpleasant action may in some measure be owing to this cause. The sudden and frequent changes of the state of the atmosphere before and during a thunderstorm, are very distressing to many people. On the whole, therefore, it may be safely affirmed that human comfort is affected to a very considerable degree by the electrical phenomena of nature.

229. The actions of vegetable life are such as cannot fail to be attended with the evolution of electricity. The great range of chemical decompositions and combinations which go on during the growth of plants, is a sufficient cause of an abundant electrical excitement. Observations and experiments have shown that this actually occurs; there is a constant circulation of electricity of feeble tension in living vegetables. But although there is too little insulation or resistance by bad conductors, to cause this electricity to assume a high intensity, so as to give shocks or sparks, the quantity of it may be very great, and it may contribute in some essential ways to the maintenance of the organic life. If we consider that electrical currents are the means of conveying chemical force from one place to another, we may easily imagine that this conveyance is sometimes necessary in the growth of vegetables. A certain power evolved at the roots in the earth, or at the leaves in the air, may be required in other parts of the plant. The decomposition of the seed may give birth to an electric current which effects important changes in the expanding germ. It has been found that by causing the seed to assume an electric state opposite to what it naturally assumes, its development is retarded or checked. Hence, on the other hand, it is perfectly credible that the growth of plants may be very much quickened by communicating electricity to them by artificial methods. Minute and long-continued observation, however, is yet required to enable us to state with accuracy the precise functions of electrical excitement in organised bodies.

NATURAL PHILOSOPHY.

EIGHTH TREATISE.

METEOROLOGY.

NOTICE.

METEOROLOGY is to be regarded not so much as a distinct department of Natural Philosophy, as a very interesting application of several other branches to explain an important class of physical powers and appearances. The principles employed in its elucidation are chiefly derived from the laws of Heat, Pneumatics, Astronomy, and Electricity; and the subject will be of easy apprehension according as the student has made himself familiar with these sciences. In the preparation of the present Treatise, the Author has endeavoured rather to embody principles, than to occupy space with details of phenomena; his aim being to render Meteorology a subject of scientific study, not a mere record of unexplained facts and elaborate observations.

ALEX. BAIN.

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METEOROLOGY.

1. **Meteorology** explains the laws which regulate weather, seasons, and climates. It involves particularly the consideration of the atmosphere, whose changes and fluctuations, caused by the influence of the sun, and modified by the peculiarities of the earth's surface, are the phenomena to be treated of. The characters or properties of the atmospheric ocean which are of importance in this subject are—its magnitude and height above the surface of the earth; its weight or pressure and elasticity, and the gradations of these as we ascend; the materials and manner of its composition; and the alterations made upon it by heat and cold. It is by an accurate knowledge of these that we are enabled to understand the nature and causes of the incessant movements and changes going on in the air around us, and of the ever-varying appearances of the sky over our head; including the phenomena of winds and storms, of rain, dew, hail, snow, mists, and clouds, and their connections with one another, and with seasons and places.

THE ATMOSPHERE.

Its Composition—General Structure—Density—Pressure.

2. The atmosphere has been already described as a vast ocean of invisible gaseous matter, enveloping the terraqueous globe, and extending to a considerable height. Although it cannot be seen by the eye, it is yet felt to be an inert material

mass, which resists bodies in their motion through it, and when set in motion itself, possesses momentum or impetus, like a flying ball or a running stream. The power of the wind exhibits the momentum or impulsive force of air in motion. From the lightness of the air, its stroke is not so great as the shock of a water-current moving at the same rate; it is as much less as the density is less. Water being 800 times as heavy as air, a stream of water moving at the rate of a mile per hour would have the same momentum as a stream of air at 800 miles an hour; but the stream of air would, from its suddenness, be the more destructive of the two. Currents sometimes arise in the atmosphere so strong as to tear up trees and sweep houses from their foundations. The atmosphere is therefore a real material substance, in a state that does not affect the sense of sight, but capable of resisting motion and of communicating force, like any solid or liquid body, in proportion to its specific gravity or density.

3. The second property of the atmosphere, proving its genuine materiality, is its weight or pressure. It presses upon the earth, exactly as the sea does, under the influence of gravitation. This pressure is in proportion to its quantity and its natural or specific gravity. When we ascend to a great height above the ordinary level of the ground, as to a mountain top, the pressure is diminished, because the quantity lying above becomes less. At the sea-level the average pressure is 14⅔ lbs. on every square inch; it is nearly the same as the pressure of a lake of water 33 feet deep, or a lake of mercury 2½ feet deep. The experiments for proving the weight of the air have been fully detailed under PNEUMATICS. The construction of the barometer, or instrument for constantly measuring this weight, and showing the degrees of its fluctuation from day to day, has been explained under the same head. By it the air is made to sustain a column of mercury, which is higher or lower according as the whole weight of the atmosphere above increases or diminishes; and therefore, by looking at the height of the mercury, we know at any instant the weight of the atmosphere at that spot.

4. Until the invention of the barometer, it was not known that the air had weight at all; still less could it have been supposed that this weight was greater at one time than at another, seeing that weight is an exceedingly constant property. In fact the changes in the weight of the atmosphere are owing solely to its movements, which cause it to shift from place to place, and for a time increase the amount over one spot, at the expense of other spots, where it is shown to be lightened. The average height of the mercurial column

is somewhat less than 30 inches at the level of the sea; but it fluctuates to such an extent, that it sometimes descends to 28 inches, and sometimes rises to 31. A low barometer proves that some cause or other has carried away a mass of air from that particular locality; and a high barometer proves that the opposite action has taken place. In either case, the extreme state does not commonly endure: the law of fluids tending to find their level, holds in respect to the air; the deficient places become filled up, and the places where there is an excess fall away all around, and an equality comes to be restored; which, however, rarely lasts long, in consequence of there being causes at work that are perpetually disturbing it.

5. The atmosphere is therefore to be considered as a mass of gaseous or aërial fluid enveloping the earth, and pressing on its surface with a weight amounting to $14\frac{2}{3}$ lbs. (14·7) on every square inch. This fluid is found to be not a single substance, but a mixture of several substances, totally distinct in their properties, and serving quite different offices in the economy of nature. The two chief ingredients—nitrogen and oxygen—which make up more than $\frac{29}{30}$ths of the whole mass, are as different in their character as water and alcohol. The proportions of these two are very nearly 77 of nitrogen to 23 of oxygen by weight; that is, 100 pounds of air contain 77 lbs. of nitrogen and 23 lbs. of oxygen. The nitrogen is therefore the principal element in point of quantity; but the oxygen performs the greatest variety of functions: it is the supporter of life, and the indispensable agent in combustion, in putrefaction, and in many other natural processes.

6. Deferring in the meantime the consideration of the other ingredients of the atmosphere, we have to study in the first place the mode of mixture of these two gases, and the general structure of the mass they compose:—

7. Although the mechanism and constitution of a gas are not apparent to our senses, yet we can infer with certainty that it is made up of atoms which keep one another at a distance by a repulsive force. From the fact that any gas can be compressed into a very small fraction of its ordinary bulk, we are sure that its particles are usually at a great distance from each other in comparison with their size. Thus, for example, it is almost perfectly safe to assume that the distance between two adjoining particles of common air is not less than a hundred times the breadth of a particle. Hence the actual occupation of space by aërial particles must be very small; on the supposition now made, there would be only one cubic inch of solid or impenetrable matter in a million of

cubic inches of space. If we imagined a flight of crows, each fifty feet every way apart from the next, we should have some idea of the spread of gaseous atoms in empty space.

8. If we take, then, any single gas, such as nitrogen, we may be certain that its particles stand asunder from each other at very great distances compared with their size; and these distances are all equal, for the nature of the repulsion is such, that there is no rest nor stable balance if a particle is nearer its neighbour on one side than on the other. The repulsion increases the closer they come; and when one is unequally near to two others, it is more repelled by the nearest than by the farthest, and is accordingly driven off till it attain an exact middle position. Thus, throughout, the distances are maintained perfectly equal; any additional compression on one side extends itself immediately through the whole, till equality is established. Two particles of the same gas can never come perfectly close to each other. It is certain, for example, that since the creation no one particle of atmospheric nitrogen ever came into contact with another particle: the repulsion becomes more intense at every step of approximation, and no ordinary force can bring them nearer than certain fixed limits. The same is true of oxygen, or of carbonic acid, or of any other gas taken by itself. Some gases, by great compression and cooling, may be liquefied, and thereby acquire the closeness and cohesion usual in liquids; but while they continue in the aërial or elastic form, the resistance arising from their mutual repulsion defies all efforts to bring them together.

9. Such is the character of any single gas; but when two gases are mixed, the circumstances are changed. We are still sure that each will repel its own kind, but we cannot say beforehand whether or not the particles of one kind will repel the particles of another kind. It is possible that a particle of nitrogen may repel a particle of oxygen as strongly as it repels another particle of nitrogen; in which case oxygen and nitrogen atoms would be kept as far asunder as atoms of the same kind. But it is also possible that nitrogen, which repels nitrogen, may be perfectly indifferent to oxygen, neither repelling, nor attracting, nor in anyway affecting it; and in this case oxygen and nitrogen particles may stand far or near as accident may determine: they may come close together, or they may move off to any distance, according to the forces exerted upon them by their own kind. It is as if we introduced among the crows, already supposed scattered at a rigid distance of fifty feet, a flock of pigeons, held apart a hundred feet from one another, but not under any repulsion

from the crows; so that while the distances of each kind among themselves are equal and fixed, there would be the greatest variety of distances between pigeons and crows, from close contact to a hundred feet. Considering also the immense amount of empty spaces between the crows, the admission of the pigeons would be almost as free as if the space was altogether empty; there would be very rarely an actual collision, and there being no other kind of mutual action except collision, each kind might move and expand almost as if the other did not exist. There is a third possible variety of relation which might obtain between the two strange gases; a particle of the one might *attract* a particle of the other, while repelling one of its own kind. An oxygen atom might have a tendency to move towards and cling to a nitrogen atom, so that whenever they came near enough, they would actually close and adhere so far as they were allowed by the repulsions to which they are subject. It is as if, while pigeon keeps off pigeon, and crow is at a strict uniform distance from crow, each pigeon had an attraction for each crow, and a pigeon and crow always ran together when they had an opportunity. As in this case we should find many instances of a pigeon and crow joined together, so in the atmosphere we should have every now and then compound or mixed atoms, although we never could have two of one kind in close companionship.

10. Now it is only by an appeal to fact that we can say which of these three relations occurs between different gases diffused through each other. It seems likely, although it is not perfectly proved, that the first supposition is not the correct one; the particles of one gas do not appear to repel the particles of a second gas, as they do one another: the repulsive tendency is confined to the particles of the same kind. Oxygen probably does not repel nitrogen, so that there is no obstacle towards the proximity of the two, except the repulsion of each to its own kind. Hence the presence of one of these gases in a space can have little effect in preventing the rise and diffusion of the other. It is not so certain from the facts, whether oxygen and nitrogen are perfectly indifferent, or whether they have a slight attraction. There are many analogies which render it likely that strange gases may in some cases attract each other. The strongest likelihood is founded on what takes place so often between liquids and solids, and between liquids and airs, in the phenomena termed capillary attraction and solution. When sugar is absorbed and dissolved in water, it is in consequence of each particle of water possessing an attraction for a particle of sugar; and

airs are extensively dissolved in liquids in the same way. This is a very wide-spread, although not a universal action: any substance will not necessarily show this kind of attraction for any other, but it holds between a very great number of substances. Thus water adheres to more than half of all the bodies in nature. The air of the atmosphere has also a high degree of adhesiveness to many substances, solid and liquid. It is therefore likely that oxygen and nitrogen may have this kind of attraction, which would cause a very frequent pairing of the particles of the two. It is still more likely that the vapour of water, which exists in the air along with oxygen and nitrogen, adheres to these other gases, since they are known to be held in solution in water in large quantities by virtue of the solvent adhesion. On this supposition the atmosphere would be made up partly of single particles of oxygen and nitrogen, and partly of double particles formed by the occasional adhesion of the one kind to the other.

11. Taking the entire mass of the atmosphere, considered as an ocean of gaseous or elastic fluid, its density must diminish as we ascend from the earth. The tendency of air being to expand to the utmost limits allowed, it would fly off into the boundless regions of space, if it were not kept on the earth by the force of gravity or by its weight. The portions at the earth's surface not only lie upon it by their own weight, but they are compressed by the weight of all that lie above them; and in consequence they are compacted into a smaller bulk than they would otherwise have. In fact each mass of air will in general contract, and become closer by being compressed, until its internal elasticity or spring is equal to the force which compresses it; and at that degree of closeness it will remain. The bulk occupied by any amount of gas diminishes exactly in proportion to the weight laid upon it. Thus if a cubic foot of air at the earth's surface (which owes its actual density to a compression of 14⅔ lbs. to the square inch, arising from the weight of the whole height of air lying over it) were pressed with a weight of 29⅓ lbs. to the square inch, its bulk would be reduced to half a cubic foot; or if half the usual weight were taken off, and the pressure reduced to 7⅓ lbs. to the square inch, it would expand to the bulk of 2 cubic feet; and so on. Hence if we ascend so high, that one-half of the air would be below us and the other half above us, the compression would be only 7⅓ lbs. to the inch, and the air would be twice as rare as at the earth, or it would have only half the density. Two cubic feet of such air would be equal in weight to one cubic foot of air taken at the earth's surface.

12. The density of the air therefore diminishes upward in the exact proportion of the diminished weight of the mass. It can be determined by calculation at what heights the weight and density will be of any given amount. Thus at 20,000 feet above the sea, the density is less than half that at the earth's surface; on the highest summits of the Andes or Himalayahs, it is about one-third, or 3 cubic feet of air weigh no more than 1 cubic foot at the sea-level.

13. There is another cause besides the decrease of weight to affect the decrease of density—namely, the increased capacity of the rarefied air for heat. If a cubic foot of air is allowed to expand to 2 cubic feet, it requires to absorb additional heat into its mass in order to keep up its temperature. It is said to have acquired a greater capacity for heat; and if it do not receive an extra quantity, it will cool down, or it will have a much lower temperature than in its former state. So that the air at 10,000 feet of height will, by its expansion, require more heat to keep up the temperature; and as it has no means of getting more than the surface air, but, in fact, receives rather less, it will be very much colder than the air below. The first consequence of this cooling is a loss of elasticity, which causes it to contract under the pressure to which it is subject, and to occupy a smaller space than it would have occupied if the temperature had been kept up by a new supply of heat. Thus a cubic foot of air, when half its pressure is taken off, becomes 2 cubic feet, only on the supposition of receiving so much heat as to make the 2 feet as warm as the 1 foot; failing this, it cools down, and contracts to somewhat less than 2 cubic feet; so that when this new cause is taken into account, the density of the air does not diminish quite so fast as the weight diminishes. The whole atmosphere is more compressed or more dense than if the law of diminished weight and density were to hold strictly; we do not require to ascend so far to pass through a certain amount of it—that is to say, we shall reach the point of 7½ pounds pressure at a lower level. In the one case, the atmosphere lying at the height of 30,000 feet would weigh about 5 pounds to the square inch; in the actual case, it is less than 4 pounds. If, in the first case, the barometer stood at 14 inches at a height of 20,000 feet, in the second case it would stand at 12 inches; showing that the contraction by cooling increases the amount below, and diminishes the weight lying over, any one given elevation. The fall of temperature corresponding to this degree of contraction would be about 70° or 80°; if the thermometer were 32° at the earth's surface, it would be 40° below zero at the

height of 20,000 feet, while the barometer would indicate 12 inches of pressure.

14. The following table gives the decrease of the air's density and pressure, on the supposition that an equal temperature is maintained throughout, or that heat is supplied to make up for the increased capacity of the expanded air. The first column gives the height in feet; the second the weight in inches of the barometer; and the third the density in decimals, the density at the earth's surface being reckoned 1. The temperature is supposed to be freezing, or 32°:—

Height in Feet.	Barometer Column in Inches.	Density.
0	30·000	1·00000
5,000	24·797	·82656
10,000	20·499	·68321
15,000	16·941	·56472
20,000	14·000	·46667
25,000	11·575	·38582
30,000	9·569	·31890

15. In this table it will be found that the density is exactly as the pressure; that is, if we take any one height, such as 20,000 feet, the barometric inches are 14, and the density ·46667, which numbers are exactly the proportion of 30 to 1, or the proportion of the number of barometric inches to the number expressing the density at the surface; and this proportion of 30 to 1 will be observed in all the other cases.

16. When allowance is made for the effect of the increased capacity of the air for heat, with the cold and contraction thence arising, the weights and densities are modified as in the following table, which exhibits in the fourth column the decrease of temperature at each height, beginning at 32°:—

Height in Feet.	Barometer Column in Inches.	Density.	Temperature.
0	30·000	1·00000	32°
5,000	23·949	·82656	14·8
10,000	19·106	·68321	— 3·1
15,000	15·229	·56472	—22·4
20,000	12·044	·46677	—43·6
25,000	9·579	·38582	—67·5
30,000	7·566	·31890	—95·1

17. It will now be seen, generally, that the barometric column diminishes faster than in the previous table, and that each successive layer contains a greater weight of air. Thus

the lowest stratum of 5000 feet weighs 5·203 inches of mercury in the first table, and 6·051 inches in the second—these numbers showing the decrease of pressure at the height of 5000 feet, and there being a fall of the thermometer amounting to about 17°.

18. In this way the atmosphere goes on, becoming rarer and lighter, and at the same time colder, as we ascend, until it ceases altogether. At what height it actually terminates we do not at present know; it can be with certainty affirmed to extend to 50 miles from the earth, as at this height it exercises a sensible effect in refracting light; but for anything that is known, it may extend to 80 or 90 miles. Its own elasticity would carry it away without limit, if something did not counterbalance the expansive force. But the weight of the particles, or their gravity towards the earth, serves as a counterbalance on the one hand, and on the other hand, the cooling caused by extreme rarity diminishes the force of the elastic spring; so that where the diminished elasticity is no more than a balance for the weight, there the atmosphere will terminate. For a few miles below this termination, it must be extremely rare, or little else than a vacuum. For all practical purposes, therefore, the height or depth of the atmospheric ocean is at present assumed as about 50 or 60 miles; but the great body of it is accumulated near the earth's surface. In reality, one-half of its material volume lies within 3 miles from the earth, and three-fourths of it within less than 6 miles. Its pressure on the highest pinnacles of the earth's surface is less than one-third of the whole weight as experienced at the sea-level.

19. In examining the nature of the atmospheric fluctuations which give rise to meteorological phenomena, the principal agent to be studied is heat. All the movements and changes to which the air is subject originate, some way or other, in the application of heat. So long as an equal temperature is kept up, the air continues at rest; but the slightest addition or subtraction of heat in any part of it leads to a series of movements that may extend to a great distance all around. The nature of these movements requires to be distinctly explained:—

20. If the temperature of the whole surface of the earth, being at first supposed everywhere the same, were to rise equally at once, the effect would be to expand and elevate the atmospheric ocean without producing any other movement. The upper surface would stand higher, and the equal divisions of the mass would also be higher. The point where the barometer is exactly 15 inches, or the middle point of the

mass as regards quantity, would stand at a higher elevation; and at the place where the mercury was formerly 15 inches, it would now exceed 15 inches; and the like would happen in other places. The weight at the surface would be the same, but at all heights above that point the barometer would rise, showing that a greater amount of air was buoyed up into the higher regions.

21. When, therefore, we suppose first, that the whole surface of the earth is of the same temperature, and next, that an equal increase takes place all over, the only effect which happens is a swelling out, or upward expansion of the whole body of the air. There are no side motions or horizontal currents created; each column is lengthened, but its particles remain over the same spot as before. But if we now suppose that the surface of the earth is unequally heated, as in fact it is, a new action will ensue. If one portion is warmed, while the portion next to it remains the same—that is, if two adjoining spots of ground are of unequal temperature, and communicate an unequal temperature to the columns of air lying upon them—the column which is most heated will be expanded in its whole length, so as to overtop the other, and it will be made rarer or lighter all through. Two effects will arise from this—the first in consequence of the elevation of one column above the other in the upper regions, and the second in consequence of the air below in the heated column being less dense than the air below which adjoins it in the cold column. It is a general law of hydrostatics, that a heavy fluid buoys up a light one; and if a heavy mass of air lie beside a light mass, the heavy will flow in upon the light, and buoy it upwards, until the different portions are arranged in the order of their specific gravities—the heaviest being at the bottom, and the lightest being at the top. Thus in the case we have supposed, of a cold column of air adjoining to a warm and lighter column, a motion will arise from the cold to the warm, which will continue until all the air at any one level is of the same specific gravity, or until each stratum is of one density throughout both columns. A lateral or horizontal movement of the air from the cold to the warm column is therefore what will take place *below*, or at the earth's surface, in a case of unequal heating. But if we consider the condition of the two columns *above*, or at their upper ends, we will find that the opposite effect must arise; that is, a movement will take place from the warm column to the cold; for the warm column being to some extent lengthened or elevated, a considerable mass of it will be thrown farther up than an equal mass of the cold column.

For example, the place where the warm column weighs 5 inches of mercury will be higher than the place where the cold column weighs 5 inches; or it will be opposite a place in the cold column where the air weighs less than 5 inches, and is consequently less dense than in the air adjoining. Now the movement being always from the dense to the rare, in this instance it will be from the warmer column to the cold; and this movement, which will be strongest at the very summit, will extend as far below the summit as the inequality of density prevails, or as the warm column is denser than the cold. There will be a certain place somewhere in the middle where the two densities will be exactly balanced; below this the cold air will be flowing in and buoying up the hot, and above it the hot air will be flowing in and buoying up the cold; and these two movements will go on so long as there is any inequality of temperature and density: so that if we have two adjoining columns of equal mass, and if one is lengthened by heat, while the other remains the same, the lengthened column is rarer than the short column below, from increased elasticity, but is denser than the short column above, from the increased pressure arising from its matter being carried to a greater height. Not only will the uppermost portion of the long column, which rises to a point where the short column has ended, and has therefore nothing but a vacuum to flow to, have a side movement towards the other, but portions far beneath the top will have a pressure so much greater than the contiguous portions of the shorter column, that they too will flow out laterally, and determine a current tending to equalise the difference of heights and pressures. The greater the difference of temperature of the two adjoining places, the more intense will both the movements be, or the more rapidly will the cold rush towards the hot below, and the hot rush to the cold above.

22. When a difference of temperature exists between two spots that lie near one another, the effect of the aërial currents which take place between them is to equalise the temperature; the cold air is brought into contact with the hot ground, and the hot air with the cold ground, and gradually the heat of the one is reduced, and that of the other raised, till both become exactly the same. The air lying over them will then be the same, and all movement will cease. Thus the lateral currents arising from differences of terrestrial heat tend gradually to abolish those differences, and bring all to one uniform pitch. The air is the carrier of warmth from over-heated to under-heated localities, and moderates both extremes. Its lateral currents are the effect of unequal heating, and in some mea-

sure the remedy. These lateral currents are felt and recognised by us under the name of *winds*. If the differences of warmth that originate them were only limited and temporary, the carrying of heat to and fro would bring about an equality, and then the air would come to a perfect repose; but these differences of warmth are perpetually kept up, and notwithstanding all the influence of the under and upper winds, they exist to a very large amount; hence the lateral currents go on for ever without ceasing. The middle band of the earth, or the equatorial zone, is exposed to the burning radiance of a direct sun, while the two polar regions are so faintly heated, that snow never melts upon them; and this great standing inequality keeps up two grand sets of movements, which encompass the globe. The equatorial air being warmer and lighter below than the air on each side, it is buoyed up by the cold masses moving in upon it from north and south, and thus two great under currents are maintained between the poles and the equator. The equatorial mass being expanded far upwards, overtops and overpresses the upper portions of the colder columns on each side, and therefore flows in upon them on both sides, making one movement towards the north pole, and another movement to the south pole; thus causing two great upper currents towards the poles, while the under currents are moving from the poles. The inequality of the equatorial and polar regions in respect of heat is thus in some degree mitigated; but it is by far too great to be entirely done away. If there were no such currents, the equator would be hotter, and the poles colder than now; but even as it is, the difference is enormous, and causes the two vast and incessant movements which we have now endeavoured to describe.

23. We have supposed, for simplicity's sake, that the atmosphere is divided into an equatorial and two polar masses; but in reality there is a constant gradation from the equator to the polar regions, and the movements will take place between every two adjoining portions of atmosphere, of which one is farther north or south than the other. The interchange will be incessant and uninterrupted, but this will not alter the great general result. Every mass of air on a high latitude will be lower at the top, and denser below than a mass on a lower latitude; and the two sets of lateral currents will be created between them. The equator will exchange its air with the temperate regions, and the temperate regions with the frozen regions, and the effect will thus be handed over from one place to another, the general course and direction remaining the same.

24. The rapidity of the two currents will be greatest, the one at the surface of the earth, and the other at the summit of the atmosphere; because in these places the difference of density is greatest. As we ascend, the densities will be more nearly equal, and the movement will be so much feebler, until we reach the point of repose, or the undisturbed stratum, where the densities are the same: above this level the difference will begin again in the opposite direction, the warm column being the denser of the two; and as soon as the difference commences, the upward current will be set in motion, and will become stronger and stronger as we ascend, and as the pressure of the light and elevated column surpasses more and more the pressure of the other. For a considerable space in mid-air there will therefore be almost a perfect calm; or for a certain way on each side of the level of equal density the motion will be very slight. There will always be a position of dead stillness between the regions of the upper and the lower winds.

25. Although, as a general rule, the temperature of the earth decreases from the equator to the poles, this is not strictly or at all times true. Various causes occur to render a high latitude as warm as, or warmer than a lower, and in such a case a contradiction will arise to the general movement, which will have peculiar consequences. Let us suppose, for example, that the air at 60° of latitude is warmer than the air at 50°, and that between these two columns there is an interchange in consequence, while an opposite interchange of double currents is going on on each side of them; that is, there are upper and under winds between 40° and 50°, and between 60° and 70°, in one direction; and between 50° and 60° in the contrary direction. The air at 60° is warmer than the air on either side; for by the general law of decrease, it is warmer than the air at 70°, and by the present supposition, it is warmer than the air at 50°. In consequence of this, there will be an under current towards it, and an upper current from it on both sides; but the upper current towards the latitude of 50° will encounter the upper current from 40° to 50°, and the two masses of air meeting will obstruct each other's course, and cause an accumulation to take place over some one spot near 50°, which would therefore from this cause have a more than ordinary pressure; and the barometer would stand there above its usual height, were it not that the under currents are similarly affected in the contrary direction; that is, the air will flow out below from 50° at both sides, just as it flows in from both sides above, and a compensation will be thus effected. The lower current between 50°

and 60°, and the upper current from 60° to 50°, would be both reversed for some way; or if the increase of temperature at 60° is not sufficient to cause a reversal of the movements, it will diminish the velocities of the regular currents in those parts. The lower wind from 50° to 60° would be weakened, and also the upper wind from 60° to 50°, and throughout this zone there would be a partial stagnation, which would be made up for by the increased vigour of the action between 60° and 70°; for the difference of temperature between these two latitudes would be greater, just in proportion as the temperature at 60° was elevated above its natural pitch. It thus appears that interruptions in the steady decrease of the earth's heat from the equator to the poles, will affect the velocity of the passing currents; these will be arrested according as the decrease of the heat is arrested, and quickened as the decrease is quickened. The rapidity of the passing winds in any one place will determine whether the regions north and south of that place are very nearly equal, or are very unequal in temperature. Every dead calm that happens at the surface is a proof that the regular law of the decrease of temperature from the equator to the poles, is suspended somewhere in the neighbourhood where the calm occurs. The legitimate places of calm are the reposing stratum between the upper and under currents, and the equatorial line where the opposite under currents neutralise each other. All other calms are the result of irregularities, or departures from the relation of temperature to latitude.

26. The gradual decrease of the earth's temperature from the equator to the poles will thus maintain the two great movements which pervade the whole mass of the atmosphere; and the air over the equator will stand permanently higher than the air over the poles; that is, the height of the atmosphere will be greatest where the heat is greatest, and will diminish as the temperature falls, being least at the poles. Thus the atmosphere encompassing the equator will be bulged out beyond the thickness that it has in high latitudes. The pressure of the air at the surface will nevertheless remain much the same; but at equal heights it will be different in different latitudes. The barometer will stand higher at an elevation of 10,000 feet over the equator, than at the same elevation elsewhere, owing to the elevation of the column by the greater degree of heat.

27. If we now take the case of the heating of the air, not at the surface of the earth, or the base of an atmospheric column, but at some high elevation, a new train of consequences will result. Let a portion of air, from 10,000 feet upwards,

receive an accession of heat, while the temperature of the portion below remains the same. The first effect will be an expansion and rising of the whole length of the column above 10,000 feet; the upper regions will have thus an increased pressure and overflow all around. If the equatorial current is passing along these regions, it will be met and resisted by this local current, and on one side the equatorial air will accumulate unduly, and on the other side there will be a deficiency. There is here a movement created above, *without a counter movement below*, and consequently air will be flowing away from the heated column, and no new air flowing in; hence its quantity or pressure will diminish, and the barometer, which measures the pressure, will fall. Suppose the heating now described took place at latitude 50°, the upper portion of the column at 50° would be expanded, and its pressure against adjoining columns increased; it would overflow north and south, east and west, without compensation below, and the barometer over 50° would fall, while the barometer all round would rise. This would happen on the side next the equator, because there the upper equatorial current would be kept and accumulated, instead of passing along at its ordinary rate; and the side next the poles would be in a great measure robbed of its usual stream, and would receive instead the overflowing of the heightened column at 50°; and in so far as the one effect did not compensate for the other, the barometer would be disturbed there likewise.

28. If a sudden cooling were to take place at a great elevation, and were to extend upwards and not downwards, the opposite effect would be produced: the upper atmosphere would contract and sink, and the surrounding masses would flow in upon it, while there would be no outward flow beneath to counterbalance the action; hence an unusual accumulation of air would take place, which would show itself in raising the barometer. Thus a heating of the upper regions over any one place makes the barometer sink, and a cooling makes it rise. This is Professor Daniell's opinion as to the immediate cause of barometric fluctuations in general, which have been a subject of very great difficulty, and have received a great number of varying explanations.

VAPOUR OF THE ATMOSPHERE.

Vaporisation—Dew—Mist—Clouds—Rain—Hail—Snow.

29. Next in quantity to nitrogen and oxygen, although very small compared with these, is the vapour of the atmo-

sphere; that is to say, the gaseous water or steam that is constantly present in it. Although very trifling in amount, this portion of the atmosphere is of immense importance in its effects. Unlike the other gases, it is easily reduced from the aërial to the liquid form, or to water as we usually find it; and it is constantly going through the processes of becoming liquid, and descending to the earth, and again rising into the air in the gaseous or invisible form. The great agency connected with these transformations is heat. When water passes into steam, it takes in a large amount of heat, which is rendered insensible to the feeling or to the thermometer; and when steam or invisible vapour is condensed into water, all this heat is given out again.

30. It is essential to bear in mind that true gaseous water, steam, or elastic vapour of water, which all mean the same thing, is invisible, like the other portions of the atmosphere; and that the white cloud that appears at the chimneys of steamboats and locomotives, and at the spout of a kettle, is not gas or elastic vapour, but vapour partially condensed, whose particles only require to be brought together to become drops of water. The elasticity, or the mutual repulsion of the atoms, is at an end when the steam becomes visible; likewise the latent heat has passed out of it; and thus it has lost the main features of a gas, and made an approach to becoming a liquid. There is nothing wanting to complete the change but the adhesion of the particles, which in cloud are a sort of watery powder nearly approaching to sea-spray, or water spread out into something like dust. Mists, fogs, and clouds are of the same character: they are not gaseous steam, but precipitated watery particles destitute both of mutual repulsion and of the latent heat of steam. When these particles get close enough, they freely adhere, and become drops of water, and descend as rain. It is impossible to make the particles of a true gas adhere—their mutual repulsion prevents it; but if the latent heat is made to pass away, the repulsion is at an end, and nothing hinders them from coming close and cohering into liquid drops. All visible vapour, therefore, is an intermediate state between elastic invisible vapour and water; it is in the state where the elasticity or repulsion has departed, while the aggregation into a condensed liquid has not taken place. If the atmosphere contained nothing but true steam, it would be transparent and cloudless.

31. The formation of steam out of water is most conspicuous in the process of boiling, where the surface is kept in an intense bubbling state, each bubble containing a mass of steam, which forces its way up into the air. This boiling takes place

at 212° of the thermometer, called for that reason *the boiling-point.* The steam thus formed has an elastic force equal to the pressure of the atmosphere, or a force of $14\frac{2}{3}$ lbs. to the square inch; that is, when admitted into the cylinder of a steam-engine, below the piston, it forces the piston upwards with a power that it would take $14\frac{2}{3}$ lbs. on the square inch to balance; or a piston of 10 square inches would be buoyed up as with a weight of 146 lbs. The reason for the *violent* escape of steam at 212° is, that it has attained a force equal to the weight of the atmosphere pressing on the water, and is therefore able to set aside this pressure, or make its way in spite of it. But even at temperatures below boiling, water passes into steam slowly and invisibly. It is well known that a wet surface soon becomes dry; in other words, that the water upon it disappears. Water, however, cannot be annihilated, or pass out of existence (it is impossible to annihilate any substance that has weight); in the drying process, the liquid water becomes gaseous invisible water or steam, and mixes with the other steam contained in the air. But for this disposition of water to pass into the aërial state, it would remain as permanent on a spot as paint or plaster.

32. The rapidity of the process of drying up, or of the passing of water into steam, depends in the first place on the temperature of the water. We have seen that it is abundant and violent at 212°; and it is less and less for every degree downwards. The elastic force of the steam produced also depends upon the temperature. The elastic force of steam at the boiling-point is equal to the pressure of the atmosphere; while the elastic force of steam produced silently at 80° is only $\frac{1}{30}$th of the elasticity of the atmosphere, or equal to one inch of the barometer.

33. Now the entire quantity of steam that can rise is limited by the temperature in the same manner as the elasticity is limited. Water at 80° will give forth vapour, until as much has been produced in the atmosphere as would counterbalance one inch of mercury; evaporation then ceases, and the air is said to be saturated with steam. Whether the steam rise freely into the atmosphere, or rise into a vacuum, no more will be produced at 80° than this quantity. If the temperature were raised to 90°, there would be the means of supporting an additional quantity of steam, and evaporation would again go on, until as much were distributed through the air as of itself would counterbalance 1·36 inches of mercury, or about $\frac{1}{22}$d of the weight of the whole atmosphere. With every new addition of heat, new evaporation would go on, which would be of the silent kind up to 212°, when the

full pressure of the atmosphere would be reached. If an extensive lake were at this extreme temperature, steam would be produced from it, until as much were diffused through the air as would press upon the ground at the rate of 14⅔ lbs. to the square inch, or sustain 30 inches of mercury; the other air of the atmosphere and the steam together would raise the barometer to about 60 inches, which is called a pressure of two atmospheres. But as the water on the earth's surface does not rise much above 80° even at the equator, and is far below this temperature in other regions, the whole weight of vapour in the air rarely amounts to one inch of mercury; so that if the pressure due to nitrogen and oxygen by themselves were 29½ inches, the whole pressure, including the vapour, would be only about 30 inches, and at the utmost 30½ inches.

34. It has been stated that at 80° vapour rises till as much exists in the air as weighs an inch of mercury, and that if the heat be increased, an additional quantity can be produced and supported. Let us now consider what must happen if the air were saturated with all that could be maintained at 80°, and if the temperature were then lowered, say to 60°. While at 80°, the vapour may amount to an inch, at 60°, it amounts only to ·52, or little more than half an inch. If, therefore, the full quantity which can subsist at the higher temperature has been produced, and if the temperature then descend to the lower point, there will be nearly half an inch too much for the reduced temperature, and this excess will be thrown out in the state of visible non-elastic vapour, or fall down as liquid drops. No more than ·52 of an inch can possibly remain in the state of invisible steam, or true gas of water at 60°; and if a previous higher temperature caused more than this to rise, all the surplus will be rejected, and made to assume some one of the forms of unelastic steam; there will be either some kind of fog, cloud, or mist, or the aggregation of these into watery coherence. Again, if the temperature were to fall from 80° to 38°, and if the full amount of vapour that could exist at 80° had been formed, then, since at 38° only a quarter of an inch can be maintained, it would necessarily happen that three-quarters of an inch would be thrown out in a visible non-elastic shape, appearing first as an exceedingly dense mist, and then depositing itself on all adjoining surfaces in wet drops: so that to find the effect of a reduction of the temperature of an atmosphere of vapour, we have first to find how much weight of true steam exists, and in the next place to determine how much can be sustained at the lowered temperature, and subtract the

one from the other; the difference will give the weight of what is necessarily converted into visible vapour. The following table exhibits the amount of vapour corresponding to each degree of temperature from zero of Fahrenheit to 90°:—

Table, showing the Elasticity of the Vapour that can be maintained at each Degree of Fahrenheit, from 0° to 90°, expressed in Inches of Barometric Pressure.

Degrees.	Inches.	Degrees.	Inches.	Degrees.	Inches.	Degrees.	Inches.
0	·061	23	·144	46	·326	69	·704
1	·064	24	·150	47	·337	70	·727
2	·066	25	·155	48	·349	71	·751
3	·069	26	·161	49	·361	72	·776
4	·071	27	·167	50	·373	73	·801
5	·074	28	·173	51	·386	74	·827
6	·077	29	·179	52	·400	75	·854
7	·080	30	·186	53	·414	76	·882
8	·083	31	·192	54	·428	77	·910
9	·086	32	·199	55	·442	78	·940
10	·089	33	·207	56	·458	79	·970
11	·093	34	·214	57	·473	80	1·001
12	·096	35	·222	58	·489	81	1·034
13	·100	36	·230	59	·506	82	1·067
14	·104	37	·238	60	·523	83	1·101
15	·108	38	·246	61	·541	84	1·136
16	·112	39	·255	62	·559	85	1·171
17	·116	40	·264	63	·578	86	1·209
18	·120	41	·274	64	·597	87	1·247
19	·125	42	·283	65	·617	88	1·286
20	·129	43	·293	66	·638	89	1·326
21	·134	44	·304	67	·659	90	1·368
22	·139	45	·315	68	·681		

35. When as much steam exists as can be maintained at the temperature which the earth and air have at the time, *saturation* is said to take place. Thus at the temperature of 70°, ·727 of an inch would suffice for saturation; and at 32°, ·199, or about one-fifth of an inch, would have this effect. But if less steam is formed than could be supported at the temperature, there is said to be a certain amount of *dryness* or *thirstiness* in the air; meaning that there is room for further evaporation. Thus if at the temperature of 65° there exists only half an inch of invisible vapour, the air is below saturation, and gives an opening for more to rise out of the water lying on the surface of the earth. The air is dry to the extent of one-tenth of an inch of the barometer; for at 65°, about six-tenths of an inch could be supported, while only five-tenths exist; evaporation may therefore go on till the additional tenth is supplied, and then the air will be fully saturated.

36. The degree of dryness or thirstiness can be measured

by the difference between the amount of vapour existing, and the amount that might exist under the temperature. Thus if the temperature were 40°, and the vapour a quarter of an inch, the dryness would be the difference between ·25 and ·264 (which is the amount sustained at 40°), or ·014; that is, $\frac{14}{1000}$ths of an inch of the barometer. So if the temperature were 85°, and the vapour nine-tenths of an inch, the dryness would be ·9 subtracted from 1·171, or ·271, which is a little more than one-fourth of an inch. It is on the amount of this difference that the rapidity of evaporation depends, or the quickness of the process of the drying up of wet surfaces. In the case last-mentioned, where the dryness is ·271, the rapidity of evaporation would be about twenty times as great as in the previous case, where the difference was ·014.

37. If the quantity of vapour in the air is less than what is supportable at the temperature for the time being, there is some lower temperature which this quantity would completely saturate. Such temperature is called the temperature of the *dew-point*. Thus if there were three-quarters of an inch of vapour existing, the temperature that this would saturate will be found from the table to be 70° (the number at 70° being ·727, or very nearly three-fourths)—that is, if the temperature were made less than 70°, this quantity of vapour would not be supported; if it were more than 70°, a greater quantity could be supported; 70° is therefore the temperature of the dew-point for this amount. It is so called because the smallest cooling below 70° would bring out visible mist, and cause dew to be formed on adjoining surfaces. The dew-point is the lowest point to which the air can be cooled down without giving out visible moisture. If the air were saturated, the temperature and the dew-point would be the same; if the air is dry, or not saturated, the dew-point temperature is below the air temperature; and the difference between the dew-point and the temperature of the air is a measure of the dryness.

38. The number of degrees of Fahrenheit between the air temperature and the dew-point temperature is not, however, the exact estimate of the dryness, as will be seen from the following example. Suppose the temperature of the air 80°, and the dew-point 70°, then the amount of additional vapour that could be supported would be found thus:—

Vapour sustainable at 80°, -	1·001 inches
... ... 70°, -	·727 ...
Difference, - - -	·274, above a quarter of an inch.

Thus a difference of 10° of temperature makes a vacancy for a fourth of an inch of vapour. Take now a difference of 10° further down in the scale. Suppose the air 40°, and the dew-point 30°:—

Vapour sustainable at 40°, - -	·264 inches
... ... 30°, - -	·186 ...
Difference, - - - -	·078, about 1-12th of an inch.

So that a difference of 10° between 70° and 80° makes a dryness or deficiency three times as great as a difference of 10° between 30° and 40°. Water would disappear three times as fast in the one case as in the other. Hence to know accurately the dryness of the air at any time, we must reduce the difference of temperatures to barometric inches, according to the preceding table.

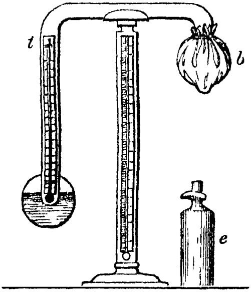
39. If vapour existed in empty space, with no other gas along with it, the quantity existing at any one time would be determined by the barometer. But as, in fact, the vapour is only a very trifling portion of the mass of gases which press upon the earth, the barometer cannot give its value separately; the mercurial column expresses only the pressure of the sum-total of the atmosphere. Hence some other means must be adopted for finding the amount of vapour by itself. Instruments used for this end are called *hygrometers;* from the Greek *hygros*, moist, and *metron*, a measure.

40. Apart from instruments, we judge of the dryness of the air, or of the additional amount of vapour which it could sustain, by the time required to dry wet bodies, such as the ground, or wet clothes hung in the air. We call that a dry day which makes water disappear rapidly from all surfaces, and which keeps the air clear and transparent. On the other hand, when wet clothes are found to make no progress towards drying, we call the day damp or moist; the air in this case being saturated with vapour. If we were to make a stone as wet as it could be, without having upon it drops of water, the time it would take to dry thoroughly, in one day compared with another, would give an estimate of the respective dryness of the days. Fogs and mists are evidence of a saturated atmosphere; and perfect clearness is a sign that all the vapour which has recently risen, or is now rising, can be supported in the gaseous or elastic state.

41. The chief instruments for determining with perfect accuracy the dryness of the air, and the actual amount of aqueous vapour that it contains—technically its *hygrometric condition*—are Daniell's hygrometer, and the wet and dry-bulb thermometers:—

42. The principle of Daniell's hygrometer is, to cool the air down upon some surface till dew appear, and to mark the temperature when this happens. Thus suppose a tumbler standing in the open air is cooled by pouring in cold water, or any other cold liquid, until the sides of the tumbler are covered with dew, the temperature of the glass at the moment that the dewing begins will be the temperature of the dew-point; for it will be the lowest temperature to which the air could be cooled without giving out visible moisture, and will therefore be the temperature that the existing vapour would completely saturate. Thus if the air temperature were 65°, and if, after pouring in cold water till dew appeared, it were found that, at the moment of dew commencing, the temperature of the tumbler were 52°, this would be the dew-point temperature, or simply the *dew-point.*

43. The construction of the hygrometer is as follows:—A central pillar or stalk has a thermometer attached to it, and carries across the top a glass tube, bent down at each end, and terminating in two bulbs *a* and *b;* the longest branch has a thermometer *t*, inside whose ball is the centre of the bulb *a*. The tube and bulbs are perfectly air-tight, and contain a quantity of ether, which is seen partially filling the lowest bulb. The bulb *b* is covered with muslin, and the bulb *a* is either blackened or covered with a metallic coating. The inside of the tube contains, besides the liquid ether represented around the thermometer ball, an atmosphere of gaseous ether, which is expanded through its whole interior, and into the muslin-covered bulb *b*. Along with the instrument, there is used a small bottle of ether *e*, with a bent tube in its mouth, to allow the liquid to be poured out in drops. The instrument is placed exactly as in the figure when an observation is to be made; and the two thermometers are supposed to be both at the temperature of the air. The observer then takes up the little bottle, and drops ether on the muslin bulb. The ether being exceedingly volatile, evaporates rapidly, and cools the bulb; and this cooling has an effect on the gaseous ether within, and condenses a portion of it; which condensation leads to a fresh evaporation from the liquid ether in the lower bulb, and consequently to the production of cold within that



bulb, and the cold goes on increasing in it so long as ether is dropped on the muslin. The temperature of the thermometer bulb is thus steadily falling, and in the course of a short time it will descend to the dew-point temperature, and the outside of the bulb will become visibly dewed. The instant of the dew's appearing is what the observer has to note, and also the height of the enclosed thermometer at this instant, for the temperature of deposition is strictly the dew-point temperature. To make the observation more accurate, the bulb is allowed to become warm again, by ceasing to drop ether on the other bulb, and notice is taken of the moment that the dew disappears, and of the enclosed thermometer at the instant; the mean of the two temperatures—the temperature of deposition and that of clearing—will accurately express the dew-point. The thermometer on the central pillar gives the air temperature at the time of the observation, and enables the observer to ascertain the dryness of the air by determining the difference of the two.

44. The determination of the dew-point by the wet and dry-bulb thermometers depends on the effect of evaporation in causing cold. When water passes into invisible vapour or steam, it absorbs from whatever substances it touches a large amount of heat, and consequently makes the bodies from which it rises colder as it proceeds. If the surface of a pool is giving off vapour, the remaining mass of water is made colder by the action; and if a wet cloth gives off its moisture, the cloth is cooled through the loss of the heat which the rising vapour carries off: the more intense the evaporation, the greater will the cooling be. Thus if we had two pieces of cloth, one wet, and the other dry, and if both were of the same temperature, and exposed to the air, after evaporation had gone on for some time from the wet surface, it would be found to have become colder than the other; and the more so the more rapid the process of drying; so that, in a very dry atmosphere, the difference of the two would become considerable. In applying this principle to measure the humidity contained in the air, two thermometers are taken—one of the ordinary construction, which serves simply to give the temperature of the air; but the other has its bulb covered with a piece of rag, which is kept constantly wet by communicating with a cup of water by an absorbent wick. The water round the bulb will be constantly evaporating when there is any dryness in the air; and the greater the dryness, the more intense the evaporation, and consequently the greater the cooling of the bulb, from which the rising vapour derives its latent heat. Hence this moist-bulb thermometer will fall in proportion to the degree of

the evaporation, or in proportion to the dryness of the air at the time. We have therefore only to compare the two thermometers—the one giving the air's temperature, and the other a reduced temperature depending on the rate of evaporation, or the degree of thirstiness—in order to judge of the comparative quantity of moisture existing in the surrounding atmosphere. If the air were perfectly saturated, no evaporation would be going on, and the wet bulb would remain as warm as the dry bulb, and the two thermometers would stand perfectly alike. But if the moisture is below the amount of saturation, a difference will be seen. Tables are used along with this hygrometer for calculating the dew-point temperature, which is ascertained, without calculation, by Daniell's instrument. The advantage of the wet-bulb hygrometer is, that an observation can be made without much trouble; whereas a nice operation must be performed upon the other in order to obtain what is sought.*

45. The force of evaporation, or the quantity of water which is converted into invisible vapour in a given time, depends entirely upon the dryness of the air, or upon the vacancy for moisture that exists at the time; this vacancy being measured, as we have already shown, by the difference between what might exist and what does exist. For example, it is calculated that if the air were at 60°, and the dew-point 40°, about a quarter of a grain of water would rise every minute from a surface of six inches diameter. But no calculation of this kind is as yet perfectly accurate, owing to the uncertain

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* Besides the above, there are various instruments called *hygrometers*, depending on the principle of the shrinking and expanding of bodies in relation to the degree of humidity with which they are affected. Fibrous vegetable substances, such as ropes, contract by imbibing moisture; while, on the contrary, hairs and catgut (strings of violins) contract by drought. Hair has been found to be the most delicate in hygrometrical motions. Saussure accomplished the construction of a hygrometer from a single long hair, previously cleaned in a soda lye. Various philosophical toys, as ornaments for mantel-pieces, have also been constructed to indicate the dryness and moistness of the atmosphere, all on the similar principle of contraction and expansion of a hair, piece of catgut, or part of the beard of the wild oat. One of the most useful instruments of this class is a small object resembling a watch in external appearance, designed to prove the dampness or dryness of beds: a movable hand on the dial-plate points out very speedily the hygrometrical condition of the bedclothes on which the instrument is laid. Hygrometers of the kind just mentioned, however ingenious, fail as instruments of science or of rigid comparison, chiefly from the circumstance of their liability to lose their contractile and expansive energy, as well as the difficulty of making many of them possessing similar powers.

action of the wind on evaporation. The effect of a current of air, is to carry off the vapour from the surface as it rises, and leave the space free for an additional supply. The more rapid the wind, the faster every wet surface dries up. On calm stagnant days, drying is in general a very slow process compared with its rate under a brisk wind.

46. Hitherto we have considered the steam or vapour atmosphere only as it is felt upon the surface of the earth, or as pressing with its whole weight. But its constitution, as we ascend, is of the same varying character as that described in relation to the dry atmosphere of permanent gases. It has an elasticity like them, which makes it expand upwards, and become rarer and rarer, as the pressure of its weight diminishes. Were we to ascend so far as to go through half of the steam atmosphere, the expansion there would be found to be double what it is at the surface; or an ounce of steam at that height would have the bulk of two ounces at the surface, or under the full pressure; so that in this case also there is a gradation of pressure and elasticity, which it is possible to ascertain. There is also a steady decrease of temperature, consequent on the expansion and the increased capacity for heat that takes place in the upper regions, which are unable to supply the new demand for heat thus arising.

47. If there were no other atmosphere upon the earth than the atmosphere of vapour, and if the whole surface of the earth were at 32°, the constitution of such an atmosphere, in respect of pressure and temperature at different heights, would be, according to Professor Daniell, as in the following table; in which it must be noticed that the numbers for the elasticity of vapour are somewhat different from the table given under par. 34, which is taken from the one in use at Greenwich observatory:—

Height in Feet.	Elasticity or Pressure in Barometric Inches.	Temperature.
0	·200	32°
5,000	·177	28·5
10,000	·157	25
15,000	·140	22
20,000	·124	19
25,000	·110	16
30,000	·100	13

48. If we compare this table with the similar one previously given for dry air, we find one striking discrepancy, and that

is in the decrease of temperatures. The decrease in the vapour is very slow compared with that of the dry gas. At 5000 feet, the dry air sinks from 32° to 14°·8, or about 17°, while the vapour falls only 3½°. At 20,000 feet, the dry air is as low as —43°, or has descended 75°: at the same height the vapour has descended only 13°, or to from 32° to 19°. The same contrast is seen whatever be the commencing temperature. This disparity produces very important consequences, seeing that the two atmospheres are mixed up together.

49. Another peculiarity of the vapoury atmosphere is, that the quantity or amount of it depends upon the temperature. The dry gas is expanded or swollen out by additional heat, but no new matter is added, and its total pressure remains the same; but heat causes additions to be made to the quantity of the vapour. At a temperature of 80°, there is five times as much steam as at 32°; or it takes five atmospheres at 32° to make one atmosphere at 80°: hence if there were a steam atmosphere over the whole earth, depending in amount on the heat of each place, the pressure at the equator would be immensely greater than the pressure at the poles; and there would be a steady decrease from the lower to the higher latitudes: so that not only would the equatorial steam rapidly overflow towards each pole, but there would be no counterbalancing under-current, as in the dry air; and the vapour would be passed rapidly from one latitude to another, where it would be condensed, and fall as liquid water. The effect would be to distil the equatorial seas away to the temperate and polar latitudes, and from these the return would take place, not in steam, but in water currents along the surface of the earth. In the case of the general atmosphere, the cold latitudes send their lower air in upon the warm; but in the case of steam, the pressure on a warm place would be greater through its whole height than in an adjoining cold place, in consequence of the increase of the total pressure or quantity.—Such being the characters of a steam atmosphere taken by itself, we must now consider the nature of the mixture which it makes with the nitrogen and oxygen atmosphere, as previously described:—

50. The same relation subsists between the vapour and these two other gases which holds between the two gases themselves; that is, the particles of elastic vapour repel one another, but do not seem to repel the particles of nitrogen or oxygen; consequently, while they must keep their distance from their own kind, they may freely approach, and remain near the particles of the other kinds. If the particles of oxygen are, in consequence of their smaller quantity, more

widely apart than those of nitrogen, the particles of water may be supposed to be much farther apart than either; for the steam in the air is but very small in amount compared even with the oxygen. We are to conceive, therefore, a very wide-spreading set of vapoury atoms moving about in a space where there also floats two other sets of atoms, both of them much more numerous than the atoms of vapour.

51. Although there is no repulsion between the atoms of different kinds, there may, however, be an attraction: it is possible that when a particle of steam comes near to a particle of oxygen, they may cohere, and remain until something happen to separate them. We are quite sure that oxygen gas has an attraction for liquid water, because we find that a large quantity of it is always absorbed and retained in water by such a force; and we have only to presume that the same attraction remains when the liquid particles have become gaseous particles, in order to assure ourselves of the likelihood of the fact: hence it will happen that the three atmospheres will not float entirely apart in single atoms, but that there will be numerous instances of two, or perhaps three, particles adhering into one. There can never be more than three in the case of three gases; for two particles of the same gas cannot come together.

52. Professor Daniell has traced very important consequences to the disparity of the decrease of temperature in the two atmospheres of dry gas and vapour. We have seen, for example, that at 5000 feet the decrease of temperature of the dry air is from 32° to about 14°; and that the decrease in the steam atmosphere by itself would be only to 28°. Now as this steam at 28° exists in the midst of the air at 14°, it will necessarily be cooled down, by the influence of the cold mass, to the same pitch as the air, or to 14°; but with this cooling a precipitation must take place, for the amount of steam that could exist at 28° cannot be maintained at 14°, and all the surplus will therefore be thrown out as visible cloud, and fall downwards to the lower regions. At some still higher stratum the same process will be again repeated; for notwithstanding the amount thrown out at the first stage, what remains will at some high station be found too much for the surrounding temperature, and a fresh precipitation in the form of cloud will occur.

53. Hence it will happen that although evaporation is going on abundantly in the lower regions, and the temperature such as to sustain it in the invisible form at the earth's surface, yet when it rises upwards, it will come to some stratum too cold for it, and where, therefore, a certain portion must be

thrown out of the invisible into the visible state, and cause a cloudy layer to be formed. Above this the air will perhaps be clear for a considerable way, but at a certain additional height, the same excessive coldness will occur; for the air's temperature will always be decreasing faster than the temperature of the vapour, and although the vapour should have at some one place a much lower degree of heat than the air, yet the more rapid fall of the air will soon bring the two to an equality: a little beyond this point of equality the air will be the coldest, and will cool down and precipitate a portion of the vapour. Thus the natural course of evaporation is to rise clear from the earth into the lower air; then at a certain height to cause a cloudiness; above this there will be a clear space, and then a second cloudiness, and perhaps a third or fourth alternately, until the vapour become too thin and too small in quantity to be conspicuous. The greater the dryness of the lower air, the farther up will the clear region extend, or the higher will be the first place of deposition or cloudiness. If the air is near saturation below, it is impossible but that a heavy precipitation or a dense mist should begin at a very small height; on the other hand, in warm dry days, when the temperature is high compared with the dew-point, the air will be clear to a very great height; and as there are certain conditions which will cause the precipitated cloud to be quickly re-absorbed, or else taken away, on such days the air may be clear throughout its whole height. Without a very considerable dryness at the surface, however, it is hardly possible for the upper air to be kept clear, owing to the natural operation of this peculiarity in the relative constitutions of the two atmospheres.

54. When invisible vapour, or true steam, is precipitated either into water or into the intermediate state of cloud, its latent heat is given out; that is to say, all the heat that entered into it when it first passed from water into steam. In the case of a precipitation in the upper air, all the heat is communicated to the air, and serves to raise its temperature to some extent. Now we have seen (par. 27) that this is one of the cases where the upper current of the atmosphere may be increased without a corresponding increase in the under current, and where consequently the total pressure will be altered. If the air is heated and expanded in the upper regions while remaining unaltered below, the overflow or passing away of the upper air will be increased, while the influx beneath continues the same, and consequently more will be going away than there is coming in, so that the whole column will be lightened. In this case the barometer

must fall, and a corresponding rise will occur in some other places; hence a great degree of evaporation, or a very great quantity of vapour in the air, is apt to make the barometer stand low. The currents of dry air formerly mentioned do not tend to disturb the barometer; the prime cause of all its fluctuations lies in the actions of the vapour, which alter the natural gradation of temperature and pressure, by carrying heat from the surface to discharge it in the higher regions.

55. It has been found by actual observation, that the dew-point does not decrease steadily from the surface upwards, but continues at one pitch up to a certain height, and there makes a sudden fall; after which it is constant again for some distance, and then makes a second fall. These places of sudden cooling show where the cooling power of the air acts upon the vapour to precipitate a quantity of it, and to reduce the amount that is left lying above. Mr Green, the aëronaut, found at an elevation of 9890 feet, that the dew-point temperature was 64°, the very same as was observed at the same time at the surface; 1100 feet farther up it fell to 32°, showing that a very sudden decrease must have taken place between the heights of 10,000 and 11,000 feet. Similar observations have been made on mountain tops. Captain Sabine observed, on one occasion at Trinidad, the dew-point at the level of the sea to be 77°, the temperature of the air being 82°; at the height of 1060 feet the dew-point was 76½°, and the air also 76½°, and precipitation was going on; showing that he had reached the stratum where the air had fallen to the dew-point temperature, and a little below, so as to cause a precipitation to take place.

56. We must now allude more particularly to the peculiar forms of visible vapour, or the constitution of the varieties of watery substance named mist, fog, cloud, dew, hoarfrost, rain, snow, and hail. Mist, fog, and cloud, are names for nearly the same thing. When there is a general haze of precipitated vapour covering the whole sky, and coming down to the surface of the earth, it is termed a *fog*. When a white smoke is seen to rise from the courses of rivers and wet land, it is called a *mist;* but mist and fog are indiscriminately applied to the same appearance—namely, to a vapoury haze lying upon the ground. *Clouds* are the masses of haze or fog which are seen floating in the higher regions, and which do not descend to the ground.

57. It being well known that visible vapour, cloud, or mist, is not elastic or gaseous, and therefore is not supported by its expansive force like a gas, it has been always a mystery

how the clouds are kept suspended in the air. When steam is precipitated into white watery particles, they ought to fall to the ground immediately like a shower of dust; for they are no longer supported by being repelled upwards by the particles beneath them. Many explanations have been devised for this singular fact. It has been supposed that the particles of cloud are like blown bubbles, which are lighter than the air, and therefore supported like balloons. But this is contradicted by every fact which is known about the air. If they were little balloons, they could hardly be so perfectly balanced as never either to float upwards or sink downwards, as all buoyant bodies that are not exactly of the same specific gravity as the surrounding fluid must do. Neither is there any reason for these bubbles all breaking, when they come together, into drops of rain, as they would require to do to make the drops heavy enough to fall. But besides, no man can say how such watery vesicles can come to be filled with a gas lighter than the air surrounding them.

58. The only explanation yet given which is consistent with the known facts, is, that the watery particles are suspended by their adhesion to particles of air, just as drops of water are suspended from any solid body. The force of mechanical adhesion of one substance to another, is one of the most extensive powers in nature. We see it in every shape. Mortar adheres to stones, glue to wood, water drops to almost everything; solids are broken down and diffused through liquids by the same force; and gases have been proved to have a very strong adhesion both to liquids and solids. We are therefore quite entitled to suppose that a particle of water has an adhesion to a particle of air when they encounter one another in the atmosphere, just as we are sure that water on the ground has a strong attraction for the air in contact with it, or contained within its mass. This attraction upholds the vapoury particles when they are bereft of the self-sustaining power of elasticity or mutual repulsion.

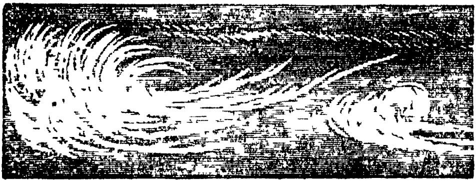
59. The steam of a kettle when it becomes visible, the white cloud of a steam chimney, our breath in a moist or cold day, are all precipitated moisture or mist. Sometimes this mist is rapidly reabsorbed as it spreads out, showing that there is a certain dryness or vacancy in the air sufficient to take it in among the invisible steam, when it is distributed over a somewhat larger surface.

60. If the air is exposed to a cooling, so as to bring it beneath the temperature of the dew-point, vapour must be thrown out everywhere, and a fog or mist will be formed. If, for example, the dew-point were 45°, and if a cold wind

or the decline of the day were to sink the air to 32°, then all the moisture above what can remain at 32° would be made visible, and a very dense fog would be the result. In this manner are formed the dense fogs of the polar seas, the fogs found along the courses of rivers, upon the sides of mountains, and over shoals and headlands. The difference between the temperature of the water and the adjacent land affects of course the air resting upon them; and hence the development of visible vapour in these localities.

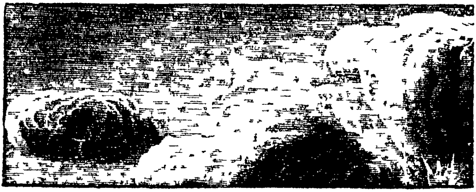
61. The celebrated fogs of London originate in the same way; but their black and thick appearance is owing to the quantity of smoke which is suspended in them. Water in every shape has an intense attraction for charcoal; and the particles are strongly seized upon by the precipitated vapour, and detained to blacken the atmosphere. This attraction would seem to prevent the ready absorption of the fog, even in the dry air of rooms. In towns where little smoke is produced, the peculiar black fogs of London never arise. The great attraction of water for almost all substances is one cause of the disagreeable effects of mists and fogs; for the effluvia that would otherwise rise upwards and diffuse themselves, are to a great extent caught and held by the free vapour, and thus kept near the surface. In stagnant foggy days, all the odours which arise from houses and works are more perceptible than at other times.

62. *Clouds* have been distinguished by Mr Howard into several classes, according to their structure and appearance. The three principal forms are the *cirrus*, or feather-cloud, the *cumulus*, or heaped-cloud, and the *stratus*, or stretched-cloud. The *cirrus* is composed of thin threads or filaments, aggregated into woolly or feathery forms, and sometimes making a delicate slender network. It is the first indication of serene and settled weather, and first shows itself in a few fibres, spreading through the atmosphere. These fibres by degrees increase in length, and new fibres attach themselves to the sides. The duration of the cirrus is uncertain—from a few

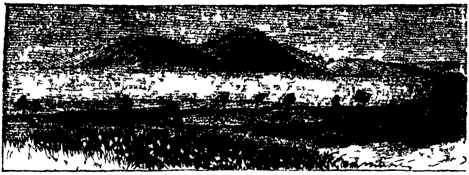


Cirrus.

minutes to several hours. It lasts longer, if it appears alone, and at a great height; a shorter time, if it forms in the neighbourhood of other clouds. From its usually curling appearance, the cirrus is called in England the *mare's-tail* cloud. The *cumulus* is the kind of cloud resembling mountains piled upon mountains, and generally ends above in rounded masses, while it is horizontal below. The appearance, increase, and evanishing of cumulus, in fine weather, are often periodical, and correspondent to the degree of heat. Generally, it forms a few hours after sunrise, attains its highest degree in the hottest hours of the afternoon, and decreases and vanishes at sunset. If the upper region, with its drying power, predominates, the upper parts of the cumulus become cirrus. But if the lower region predominates, the basis of the cumulus sinks, and the cloud becomes *stratus*, which appears as a long horizontal band of moderate density, with its lower surface resting upon the earth or the water. Combinations of the above forms have been discriminated under the names of *cirro-cumulus*, *cirro-stratus*, and *cumulo-stratus*. The black rain-cloud, which seems a general mixture and confusion of all the clouds in the heavens, has been called the *nimbus*.



Cumulus.



Stratus.

63. The *cirrus* clouds are the most elevated: they have been found as high as 20,000 feet, and they must therefore be often made up of snow particles, for even under the equator, water would be frozen at such a height. In general, we may

say of the light fleecy masses that we see on a summer day, that they are made up of snow powder, or frozen icicles. The *cumulus* clouds are evidently the precipitation of the ascending vapour in the cold upper regions; for they generally increase with the heat of the day, which disperses all superficial mists. The *stratus*, on the other hand, has more the character of a night-cloud: it is a result of the cooling of the air in the evening, and comes out in the lower regions of the atmosphere. All mists and fogs are of this species of cloud, which, in its lightest state, does not wet leaves or any objects with which it comes in contact. In calm evenings, the stratus may be seen ascending from the valleys to the higher grounds, and there extending itself in masses like a fleecy mantle. It generally arrives at its point of greatest density about midnight, or between that time and daylight, and disappears at sunrise by the gradual elevation of temperature in the atmosphere. Sometimes it remains quiet, and accumulates in layers, till the atmosphere is incapable of sustaining its weight, when it assumes the condition of the heavy and dark *nimbus*, and falls in a shower of rain.

Nimbus.

64. The various circumstances which concur to precipitate moisture in the atmosphere into the visible form of clouds, are summed up as follows by Mr Graham Hutchinson, in his "Treatise on Meteorological Phenomena" (Glasgow, 1835):—"1*st*, When a diminution of the atmospheric temperature, unaccompanied by atmospheric rarefaction or transportation, takes place. 2*d*, When a diminution of the atmospheric temperature, arising from atmospheric rarefaction, takes place. 3*d*, When a diminution of the atmospheric temperature, arising from the transportation of air from a warm to a cold climate by the agency of winds, takes place. 4*th*, When an intermixture, and consequent reduction to a mean temperature, of different portions of air, of previously different temperatures, takes place. If any one, or any combination of these circumstances, happens to occur when the atmosphere is pre-

viously saturated with humidity; or supposing the atmosphere previously somewhat under-saturated, if they take place to such an extent as to produce over-saturation, a precipitation of moisture into the visible form of cloud or mist is the necessary consequence."

65. When moisture is precipitated at night in the form of wetness, and drops on the surface of the ground and on the leaves of plants, it receives the name of *dew.* This precipitation arises when the surface of any body is cooled below the dew-point temperature. Thus if the dew-point were 45°, and if by any means a glass tumbler were cooled down to 40°, the film of air lying next to it would also be cooled down to 40°, and would therefore have to give out all the vapour which it could not hold at that temperature; but the precipitated surplus in this case would not appear as mist in the air, but would adhere to the surface of the glass. When cold glasses are brought into a warm room, they sometimes become dewed all over in this way. The bringing out of visible dew is, as we have seen, the means of determining the dew-point temperature in Daniell's hygrometer—par. 43.

66. Night-dews are most copious when the sky is clear. The reason of this is, that the earth cools faster under a clear sky than when hung over with dense clouds, which prevent the radiation of the heat. The surfaces which naturally radiate off their heat with most rapidity are the first to sink below the dew-point temperature and to become dewed. Thus rough surfaces are wetted sooner than smooth, plants sooner than glass, and glass sooner than metals. Metals being good conductors of heat, as fast as their surface cools, heat flows to it from the interior, and consequently the temperature of the surface cannot sink till the whole mass throughout has parted with its heat. Woolly and fibrous substances cool very fast, and are therefore rapidly bedewed. Locks of wool, and the like, are readily soaked with dew.

67. No dew can fall on a surface till its temperature has fallen below the dew-point; hence in the case of a very dry atmosphere there may be no dew formed at the coldest time of the night. In arid deserts, and in the countries where dry winds prevail, dew is not often seen.

68. When the surface dewed is below the freezing temperature, the vapour is not only precipitated, but is also frozen; hence the origin of *hoarfrost*, or frozen night-dew. The occurrence of hoarfrost is a proof that the temperature of the ground has fallen below 32°, as well as below the dew-point temperature. As in the case of dew, everything that prevents the radiation of heat arrests the formation of hoarfrost.

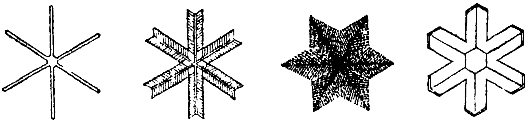
During the chilly nights of spring, plants that are sheltered by trees are less liable to be frozen than those which are fully exposed, and a slight covering of straw, or even of paper or netting, will often afford an effectual protection. Vineyards, it is said, have frequently been saved from the effects of frost by enveloping them during the night in a cloud of smoke.

69. *Rain* is the aggregation of the cloudy particles into masses or drops, which can no longer be sustained by adhesion to the particles of air, and must therefore fall to the ground. When a very great precipitation of moisture takes place, this adhesive support will be overcome, and one after another the watery particles will drop away, and in their fall attach others and carry them down also, till, after a descent of several hundred feet, each drop may contain thousands or millions of the original separate atoms. But something must happen to bring the particles near one another before they can cohere and become drops. It is almost certain that each particle of a cloud, when it is first thrown out into the visible shape, must be apart from the particle next adjoining at least several hundreds of times its own breadth, so that an extensive cohesion will not naturally arise till some commotion has first brought them closer together.

70. Rain most usually arises from the mixture of different strata or currents of air. When a warm saturated mass is acted on by a cold mass, there is always a precipitation of vapour; and besides this, the agitation and conflict of the two currents bring the scattered particles nearer each other, so as to favour their adhesion. Moreover, when the mutual repulsion of the particles is at an end, their cohesion has free play, and will instantly aggregate them to a certain extent, so that cloud will never consist of separated ultimate particles, but of minor water drops, not heavy enough at first to break away from their adhesion to the particles of air. But as the amount precipitated increases, the aggregate drops will become larger, and at last they will fall away by their own weight. There is a limit to the quantity of inelastic vapour which the atmosphere can support, just as there is a limit to the quantity of salt that water can suspend in solution; when these limits are passed, the surplus must descend to the bottom or fall to the ground.

71. The heaviest rains are always experienced where the quantity of moisture in the air is great, or where the dew-point is high, as in tropical countries, in which the showers have a weight and energy unknown in cold regions: so also in summer the rains are heaviest everywhere, although they may not be so frequent as in the other seasons.

72. When the temperature of the stratum of air from which the rain falls is under 32°, the vapour or clouds must necessarily be frozen, and the descending particles will be *snow* instead of rain. Snow-flakes are the aggregation or union of frozen particles, just as rain drops are the union of watery particles. They aggregate, according to the law of the crystallisation of water, into regular and symmetrical forms, of which the general character is a six-sided figure; as, for example, six needles branching from a centre, or six arms from a six-sided nucleus, each needle being three or six-sided. Though single crystals always unite at angles of 30°, 60°, or 120°, they nevertheless form, by their different modes of union, several hundred distinct varieties of snow-flake, some of which are figured in the preceding engraving. Any agitation of the air, or an increase of moisture or temperature, destroys of course their delicate and beautiful structure.



73. When drops of rain formed in an upper stratum descend through a stratum whose temperature is less than 32°, which sometimes happens, although against the general course of the atmospheric gradations, they are frozen into lumps or balls of ice, which we term *hail.* Hailstones are thus the consequence of an irregularity, or an exception to the ordinary and natural arrangement of the atmospheric layers: instead of the colder air being always uppermost, in this case a cold must lie beneath a warm stratum; or even several such alterations may occur.

74. The precipitation of vapour in any shape is generally accompanied with commotions and rapid movements of the air, which are called *storms.* These differ from the ordinary wind currents in being sudden, violent, and temporary.

75. Besides *nitrogen*, *oxygen*, and *watery vapour*, the atmosphere contains *carbonic acid* to the amount of about a two-thousandth part of its whole weight. This is employed by nature, along with water, in supplying the food of plants; and it is given out in the processes of combustion and animal respiration. It is diffused through the other gases of the atmosphere on the principles already laid down. *Ammonia* is also a constituent of the atmosphere, but its amount is exceedingly small. These may be said to be all the perma-

nent elements of the atmosphere, or the substances always present in it, and diffused through its whole extent.

76. From its contact with the earth, the lower stratum of the air usually contains a number of casual substances: such as the gaseous exhalations from animals and vegetables, living and dead; the exhalations from all chemical and organic processes, whether natural or artificial; the innumerable gaseous and volatile products of human habitations, villages and cities; the odours and effluvia that issue from almost every spot of the earth; the sand, dust, and fine solid particles which are carried up from the surface, and floated in the winds; the seeds of numerous plants and animalcules, which, by their minuteness and lightness, are easily carried in the air; and the subtle matters that convey the poison of disease. Most of these substances, from their injurious effect on the human system, are regarded as impurities; but their consideration does not belong to meteorology.

SURFACE OF THE EARTH IN RELATION TO THE ATMOSPHERE.

Mean Temperature — Trade-Winds — Sea and Land-Breezes — Hygrometric Changes—Fall of Rain—Fluctuations of the Barometer and Thermometer.

77. The changes and fluctuations of the atmosphere have all a relation to the peculiarities of the earth's surface, and especially to the unequal heating of its different parts, owing to the varied action of the sun, the distribution of sea and land, and the different elevations of the land. The decrease of heat from the equator to the poles causes one class of atmospheric changes; the change of the sun's place in the course of the year, or the rotation of seasons, causes another class of changes; and both of these are modified by the positions of sea and land, and by the characters of the mountains, valleys, and plains of the land surface.

78. The mean temperature of the equator is about 81°, if taken at the sea-coast, where the action of the sea keeps it more equal than in the interior of continents. If the whole earth were a perfectly smooth globe of one uniform kind of surface —that is, if it were all sea, or all one kind of level land— the temperature would decrease steadily from the equatorial amount, according to the latitude. The mean temperature at the poles cannot be known by actual measurement; it can only be inferred from the rate of decrease on to the highest latitude we know. It has not yet been agreed, however, at what it should be fixed; the most likely estimate which has hitherto been made is 45° below freezing, or 13° below the

zero of Fahrenheit. There would thus be a range of 94° between the warmest and coldest parts of the earth. If there were no other causes to affect the mean temperature besides the obliquity of the sun's rays, it would decrease steadily and regularly from the equator to the poles, and have a fixed proportion to the latitude. Thus at 10° lat., it would be somewhat above 70°; at 30° lat., it would be about 54°; at 70° lat., it would be below freezing; and so on for any other latitude.

79. By the *mean temperature* of a place is understood the average temperature for a whole year, or for a number of years. If observations were made of the temperature for every hour in the course of a day, the average of all these would be the mean temperature of the day; also the mean of the greatest and least temperatures would be pretty nearly the mean of the day. If the mean temperatures of 365 days are found in this way, and an average taken of the whole, this gives the average or mean temperature of the year. And if a great many years have been observed in the same manner, the average of the whole would be reckoned the general mean temperature of the place where the observations have been made.

80. By striking the average of the mean temperatures of all the zones of latitude from the equator to the poles, we would have the mean temperature of the whole earth, which should be very much the same as the mean temperature of the circle of latitude half-way between the equator and the poles, or the latitude of 45°.

81. The action of the sun is the chief source of the warmth possessed by the atmosphere and the ground, though not the only source. The earth itself is proved to have a permanent internal heat, which increases gradually from a point beneath the surface downwards, as far as observations can reach. But the heat that fluctuates from day to day, and which is greater in summer than in winter, and in the daytime than during the night, is derived solely from the sun; and these variations are owing to his acting more strongly at one time than at another.

82. It has already been pointed out, under ASTRONOMY, that the reason why the sun heats the equator and the regions adjoining more strongly than it heats the temperate and polar regions, is, that at the equator it rises higher in the heavens, and shines more directly downwards. The strength of the rays is always proportioned to their directness, which is most perfect when the sun ascends to the very summit of the sky, or to the zenith. Accordingly, all places where this elevation is attained at noon, enjoy the greatest possible

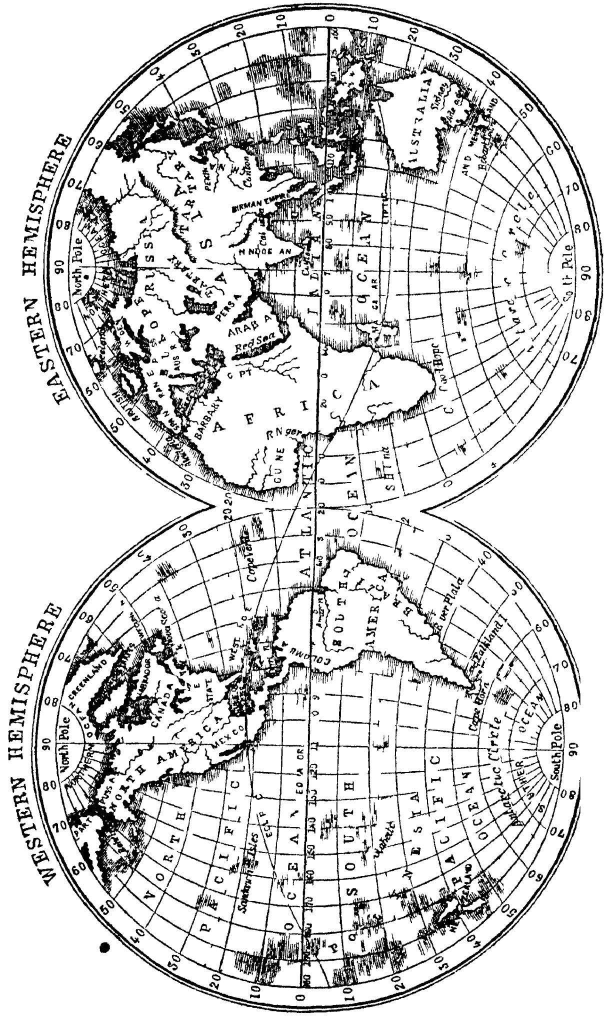
degree of heating power; but the farther away a place is from the equator, the less is the average noonday height of the sun, and therefore the smaller the influence it exerts. Now at 10° of latitude the average meridian height is 10° below the summit, and at 50° latitude it is 50°, and so on for every other latitude. At the pole the average noonday height is nothing at all, the sun being as often and as much below the horizon at mid-day as above it.

83. Although the absolute warming power of the sun's rays depends on the average height of his daily ascent, yet the force of their stroke seems to be greater in the cold regions than in the warm. In all kinds of forces, quantity is one thing and intensity is a different thing. Thus it is found that in a clear day, in the polar regions, the power of the sun's rays, when acting directly upon a surface, heats it more rapidly there than rays of the same inclination would do at the equator. Voyagers in the polar seas have observed the pitch on a ship's side melting under the sun's rays, while the temperature of the atmosphere was far below freezing; and by making observations in different latitudes, it appears that this intensity increases steadily from the equator to the poles. Such an increase is of very great importance to vegetation in the cold regions; for as the flowering of plants depends in a great degree on the direct rays of the sun, the stronger these are the faster the process will go on; and this additional intensity is some compensation for the general coldness of the earth and air in these regions.

84. This difference in the intensity of the stroke of the sun's rays is ascribed to the influence of the atmosphere through which they have to pass. It would seem that as the atmosphere is rendered more elastic, or as its temperature is increased, it exercises a greater power in subduing the force of the rays as they proceed through it. The atmosphere arrests a certain portion of the heat, and is itself rendered warm by the portion arrested. This is one source of the warmth of the air. When clouds are spread out in the atmosphere, the resistance to the rays is still farther increased, and a greater portion taken up by the air itself. The other sources of atmospheric heat are, contact with the surface of the earth, and the radiation of heat from the ground upwards. The air arrests and retains a certain portion of the heat radiated from the earth upwards, as well as of the rays of the sun passing downwards. The lower strata of the air always tend to the same temperature as the ground upon which they rest; because whichever is warmest gradually gives off its heat by conduction and radiation to the other.

85. The air exercises a very important influence in keeping up the mean temperature of the earth, by resisting the passage of heat outwards, on the same principle that our bodies are kept warm by clothing. The thinner the covering of air, the colder would the earth be; as we see in ascending to the tops of mountains, at which the temperature is always much lower than at the sea-level—the cold increasing with the height. These high places receive a more intense solar radiation through the thin covering of air that lies upon them; but such is the ease with which the heat can radiate off through a thin atmosphere, that they are always kept comparatively cold. If we had no atmosphere at all, the rays of the sun would be very intense where they actually struck, but so rapid would be the loss of heat by radiation, that the whole earth would be permanently kept far below freezing; no liquid material of any known kind could exist on its surface.

86. The first great effect on the atmosphere of the unequal temperature of the different parts of the earth, and especially of the steady decrease of heat from the equator to the poles, is to produce the two grand currents which we have already described: an upper current from the equator to the poles, and an under current from the poles to the equator. If the earth were at rest, these currents would blow exactly north and south, but the daily revolution of the globe has an effect in altering their directions. The equator, or thickest portion of the earth's body, considered as a ball revolving on an axis, moves with the greatest rapidity in the daily whirl; any place upon it is carried round at the rate of upwards of a thousand miles an hour. But the belts on each side of the equator being smaller in circumference, any point on one of them is moved with proportionably less rapidity. Thus the belt or zone at 60° of latitude has only half the circumference of the equatorial zone, or about 12,000 miles; so that a place upon it will move round only 12,000 miles a day, or 500 miles an hour. In like manner, at 30°, the rapidity of movement is about 860 miles an hour. Now the atmosphere revolves along with the earth, and every portion of it will have the same velocity as the place on which it lies. Thus the equatorial atmosphere will have a motion with the earth of 1000 miles an hour, and the atmosphere at 60° will have a motion of 500 miles an hour, from west to east. But if the equatorial air, with its high velocity, is carried away in the upper current to a place with a lower velocity, the air will still persevere in its equatorial speed, and will consequently outrun the speed of the place upon which it has come, and will be felt as a strong wind in the direction of the rotation. If equatorial



WESTERN HEMISPHERE

EASTERN HEMISPHERE

air were suddenly transplanted to 30° latitude, for example, it would be moving from west to east at the rate of 1000 miles an hour, over ground whose movement would be only 860 miles an hour; or the air would outrun the ground, or sweep over it at 140 miles an hour. This would have the effect of a westerly breeze of this degree of rapidity, and as such it would be felt by the inhabitants. Hence the upper equatorial current in moving north and south, will also have an easterly motion, from this excess of rotatory speed over the places upon which it comes. In the north hemisphere it will be a south-west wind; and in the south hemisphere it will be a north-west wind—that is, in the north hemisphere it will be felt coming from the south with a westerly character; and in the other hemisphere it will be felt coming from the north with the same westerly character.

87. A similar explanation serves to show that the under currents from the poles to the equator will not be due north and south, but will have, in addition, an easterly direction. Air from latitude 30° going upon the equator with a westerly velocity of 860 miles an hour, will move 140 miles an hour slower than the equatorial surface, or it will lag so much behind; and the effect will be felt as an easterly wind sweeping over the surface at this rate. Thus at every place the great under current from the poles will have an easterly character; or the under current in the north hemisphere will be a north-east wind, and in the south hemisphere a south-east wind. These under currents are known by the name of the *trade-winds;* because they are so steady and constant, that they can be calculated on by navigators in the tropical seas.

88. The trade-winds begin to be felt at about 30° of latitude on each side of the equator. Ships entering upon this belt begin to feel a steady easterly breeze, which continues, although with some variation, to within 2° of the equator. The two currents from north and south meet about the equator, and completely neutralise each other; and their meeting forms a belt varying from 150 to 550 miles in width, called the *region of calms and variables.* There is no steady wind in this region; its atmosphere is generally calm, having at certain seasons light southerly winds, interrupted by fearful storms and tornados.

89. The easterly direction of the trade-winds is greatest at their place of commencement, or about 30° latitude. As they pass towards the equator, they acquire an increase of westerly velocity by friction on the ground, which tends to bring up their speed to the rate of motion of the equatorial surface, so that at the equator they lose the whole of their easterly cha-

racter, and become north or south. In a southward voyage, as from Britain to the Cape of Good Hope, a ship in entering the trade-winds experiences first a breeze almost due east, which becomes more and more southerly as it approaches the equator, and is completely south at the entry to the region of calms and variables; on crossing this region, the southern trade is entered, which is at first due north, or blowing pretty direct from the equator, but it gradually shifts to the eastward, or passes from north to north-east, and finally to east in emerging from the farthest limit of the southern trade.

90. The reason why the trade-winds do not extend beyond 30° of latitude is, that there the upper current begins to be felt at the surface. The equatorial overflow falls lower and lower as it passes along each hemisphere, and at a certain distance it reaches the ground, and is experienced as a south-west wind in the north hemisphere, and a north-west wind in the south hemisphere. This interrupts the steady course of the under current, which is overborne during the greater part of the year, for a certain way on each side of the trade-winds, by the descending current. In the belt from 30° to 40° in each hemisphere, the westerly current predominates over the easterly, and the encounter of the two causes more frequent storms and squalls than are felt within the limits of the trades. It is impossible that the easterly current should be entirely suppressed anywhere in the lower regions, but it is opposed more and more as it passes from the poles towards the latitudes of 30°, and the proportion of westerly breezes increases. In the temperate zone there is an alternation of east and west winds, happening at longer or shorter intervals in the course of the year, the westerly winds being on the whole the most frequent.

91. But the two great primary currents are considerably modified by the annual course of the sun. If the sun remained always where it is at the equinoxes—that is, shining directly on the equatorial line—the limits of the trade-winds would remain fixed all the year through; but as it moves on each side of the equator, the zone of greatest heat also moves, and with it the overflowing columns of the atmosphere. Thus at midsummer, the centre of overflow, instead of being on the equator, is shifted some way into the northern hemisphere, and the parting of the upper currents, as well as the meeting of the under currents, will take place northward of the equator; and this will cause the entire belt of the trades to be moved northwards. Thus in June and July, a ship from the north would enter the northern trade before coming to latitude 30°, and would reach the region of calms before

approaching the equator, and pass out of the southern trade before attaining to 30° of south latitude. The opposite arrangement will occur in winter, when the sun's direct rays fall considerably south of the equator.

92. Hence it happens that in summer-time the region of calms is entered at from 10° to 12° distance from the equator. The region of calms itself changes its character according to the season. When it is not absolutely calm, there are light southerly winds; and about July and August a brisk south-west is found, owing to the under current from the south passing from the equatorial regions to places north of the equator, which have a less rotatory velocity; being the reverse of what happens when the meeting of the currents is exactly on the equator. About the time of the equinoxes, the prevalent appearances are light winds from all points of the compass, long calms, and occasionally furious squalls with deluges of rain.

93. The westerly winds which prevail outside the belt of the trades are shifted in like manner by the course of the seasons. They extend farther into the northern hemisphere in summer, and into the southern hemisphere in winter. Thus in Europe westerly winds are most frequent in summer and autumn, and easterly winds most frequent in winter and spring.

94. The great upper and under currents are modified by another class of currents, of a more local and limited character, arising from the distribution of sea and land, and the unequal susceptibility of these to the sun's heat. If the sun shine with the same directness and force on two tracts of surface, the one water, and the other solid ground, the ground will be most rapidly heated, and at the end of the day it will be found much warmer than the water. On the other hand, in the absence of the sun, the land cools fastest, and at the end of the night it will be found below the temperature of the adjoining water. This difference causes an inequality in the temperature of the columns of air lying upon the two surfaces. When the land is hottest, the air resting upon it will be hotter and more expanded upwards than the air over the sea; hence the cold air from the sea will rush in upon the hot in the lower regions, and the hot will fall in upon the cold above. Thus during the day, when the land is warmer than the sea, there will be a breeze from the sea to the land, and during the night a breeze from the land to the sea. These are called the *sea and land-breezes.* They rise regularly on all the sea-coasts. In calm weather, or when not overborne by other winds, they may be always observed. The sea-breeze, or the current from the sea to the land, begins at

about eight or nine in the morning; at first it is gentle, and extends only to a short distance; it gradually increases both in force and in extent till about three o'clock in the afternoon, when it begins to decrease, and gradually to give place to the land-wind which rises soon after sunset, and attains its greatest force in the morning. When other winds occur, the sea and land-breezes will of course be modified by those. Thus on a west coast, during an east wind, the sea-breeze may be suspended entirely, or it may not be felt till about noon. For the same reason, east winds on west coasts are lighter during the day than at night, but they are made so much the stronger on east coasts.

95. On coasts where a large tract of land joins a great expanse of sea, as on the coasts of America and the south of Asia, the sea and land-breezes become very considerable. The easterly trade-winds are often reversed by them. But the most powerful effect of the sea and land-winds is annual, or dependent on the seasons. In summer-time, under a high solar influence, the temperature of the land rises much above the temperature of the sea, and remains so day and night throughout the hot season. On the other hand, the sea is permanently hotter than the land in the cold season. Thus steady winds are kept up on the coasts except about the equinoxes, or shortly after, when the sea and land are nearly of the same warmth. During summer and autumn there is a constant breeze from the sea to the land, and during winter a breeze from the land to the sea. The most remarkable example of this is furnished by what are called the *monsoons*—from the Malay word *moussin*, signifying seasons—experienced along the coasts of Africa, India, and China.

96. When the sun is far north in midsummer, and shines with direct rays on the Asiatic peninsulas, the land in them is rendered very much hotter than the ocean, and a strong sea-wind sets in towards these coasts, with a direction for the most part opposite to the trade-winds, whose motion would be from these peninsulas to the sea in an easterly direction; whereas these sea-winds are towards the land, and, from the position of the coasts, are more westerly than easterly. Hence an immense wide-spreading conflict arises, which begins about the month of April, or two months before the sun has reached his extreme north declination. The first beginning of the conflict in April causes furious rain, wind, and thunder-storms, but in the course of two or three weeks the sea-breeze completely overcomes and suspends the trade-wind, and continues steadily to prevail from April to October; this is called the *south-west monsoon;* and it can

be as much calculated on for navigation as the trade-winds in their most uninterrupted regions. The influence which sustains this wind becomes gradually weaker as the sun moves southward, and in October it becomes too weak to overcome the trade-wind, and the two meeting with equal force, cause a second violent tumult of rain and storms, till in a short time the trade prevails; which then continues during the winter half-year, and forms what is called the *north-east monsoon*. These winds are found to penetrate very far into the continents, showing that the inequality of surface heat which causes them extends over a wide space.

97. Mountains greatly affect the monsoons' course, by interrupting and diverting their progress. Thus the wind which brings the rain to the north-eastern part of the Indian continent, originally blows from the south-west over the Bay of Bengal, until it reaches the Himalayah Mountains, and those which join them from the south; these check its current, and compel it to follow their range towards the north-west; but when it has continued so far towards the north-west as to meet that chain of mountains called the Hindoo Coosh, then it is by them turned off towards the west, and sweeps along until interrupted by the range of the Solimaun, which prevents its proceeding farther in that direction, or compels it to part with the clouds with which it was laden. If the reader will trace on the map the course here described, he will at once perceive the influence these mountains must possess in modifying the direction and general character of the monsoon.

98. In the Atlantic a similar action is perceived. In the summer-time, the land of North Africa is made so much hotter than the adjoining sea, that a brisk south-west or south-south-west wind blows between the equator and the southern limit of the northern trade, which is then at about 10° or 12° north latitude. The southerly character of this current might in part be owing to the influence of the southern trade, but the westerly direction must result purely from the sea and land-wind between the Atlantic and the African continent. In America also similar breezes are experienced.

99. The principle of sea and land-breezes is exemplified in a different manner in mountainous countries. The mountain tops are warmest in the early part of the day, and the plains and valleys are warmest at the decline; and there may be distinctly traced a current up the sides of the mountains in the morning, and downwards in the afternoon.

100. But the difference of sea and land gives rise to another set of atmospherical fluctuations depending on vapour. The

chief sources of evaporation are the seas, lakes, and rivers: from these the moisture rises and diffuses itself over the land; and in general it must happen that the air lying on the seas and lakes must be more highly charged with watery vapour than the air lying on the land. The interior of continents will therefore be much drier than the sea-coasts. We have seen also that the rise of vapour into the higher regions of the atmosphere, and its precipitation there in the form of cloud, has the effect of warming and elevating the upper columns, and making them overflow all round, so that a class of winds will have their origin in this influence. There will be an upper overflow from the sea to the land, and an under influx from the land to the sea, which will cause new complications and changes in the atmospheric movements.

101. The evaporation from the sea is not so great as from fresh water. The boiling-point of salt water is several degrees higher than 212°. It is said, as a general rule, that the vapour rising from sea water is no greater in amount than would arise from distilled water 6° colder; or if the sea were at 46°, it would yield no more vapour than distilled water at 40°. This makes the air over the sea much drier than it would otherwise be; and, in fact, keeps the whole earth in a drier state than if the water were pure: there is less of clouds, fogs, dews, and rains.

102. As an example of the moisture produced over the sea, Colonel Sabine mentions one striking instance. While sailing on the coast of Africa between Madeira and Sierra Leone, the wind was one forenoon from north-north-east to north-east, or directly off the land; the temperature of the air was 66°, and the dew-point was so low as 37°, indicating an enormous degree of dryness; the character of the wind approached the "Harmattan," or dry wind of the desert. In the afternoon the wind shifted to the north-west, which was off the sea, on which the dew-point rose to 60°, the air being 70°.

103. The sea-winds in passing over continents gradually lose their moisture; so that the sea-coasts receive the largest share of water in all its forms, and the most distant parts of the interior the least.

104. It is not possible for the elasticity of vapour to rise higher than 80°, or about one inch of the barometer. The highest temperature of the air over the ocean is 86°, and it can never be fully saturated. Hence the extreme heats of tropical climates and of the height of summer must always be accompanied with great dryness. Although there is three times as much sea as land, this is not more than enough to keep up a sufficient moisture for the habitable countries; for

although some regions have rather more than is desirable, many large tracts of country remain desert and uninhabitable solely from the dryness of their air and the scarcity of rain. If there had been as much land-surface as water, a far less portion of the globe would be habitable than at present.

105. The lowest stratum of the atmosphere—that is, a thickness ranging from one to four miles—is more frequently saturated with vapour than any other, and constitutes the region of the clouds. Above this there is an almost uninterrupted transparency in the sky.

106. The evaporation is necessarily greatest in the equatorial regions, where the temperature is greatest, and decreases steadily towards the poles. For the same reason, the precipitation of vapour, or the rain, must be most abundant in the warmest climates, and in the neighbourhood of the tropical seas. On the Malabar coast of the East Indian peninsula, at 11½° from the equator, the fall of rain in a year amounts to 123 inches, or to a lake of water 10 feet deep. In latitude 60°, the fall is reduced to 17 inches. In Great Britain, the annual fall is from 20 to 40 inches.* Hence in hot countries the showers have a weight and force of which we have no conception from anything we experience. The quantity of rain on high grounds is often greater than at the sea-level, especially on mountains that stand in the way of moist winds. At Geneva, the annual fall is about 31 inches; at the Great St Bernard it is 60 inches. The rain which falls on the Cumberland mountains is very great compared with the fall on the plains to the east of them. These mountains interrupt the highly-charged winds from the Atlantic, and receive a considerable portion of their vapour, rendering the air drier over the inland counties than at the sea-coast. The same influence is felt on a very large scale in South America. The air from the Pacific Ocean striking on the mountain-wall formed by the Andes, is carried up the sides of the mountains in its passage across, and so far cooled, as to give out a portion of its moisture; and the winds on the other side of the chain are found to be comparatively deficient in vapour. The great rivers in South America—the Amazon, Orinocco, &c.—derive their waters from the heavy rains of the Andes: the interior of the continent is often intensely dry.

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* The quantity of rain which falls at any station during a given time is ascertained by means of the *rain-gauge*—an instrument constructed in various ways. One of the simplest forms consists of a cylindrical copper vessel furnished with a float: the rain falling into the vessel raises the float, the stem of which is so graduated, that an increase in depth, to the extent of one-hundredth of an inch, can be ascertained.

107. Rain does not often fall in the constant trade-winds, but it is very abundant in the latitudes closely adjoining them. The vapour raised in the immediate vicinity of the equator overflows on each side, and comes to be precipitated at some distance from it. Another reason for the rarity of showers in this region is the steadiness of the temperature. In order to throw down vapour, a considerable cooling is necessary; the air temperature must fall below the dew-point. A cold current coming in upon a warm and moist air will have this effect, or a warm saturated air flowing over a tract of cold ground, or a severe cooling at night; but these causes are not frequent near the equator. But when the equatorial air, with its high temperature and high charge of vapour, goes some way into the cold latitudes, it is reduced in temperature, and can no longer contain its entire load of moisture, and rainy precipitations must ensue. Thus a constant distillation is going on from the tropical seas towards the regions without the tropics on each side. Hence, as a general rule, south winds with us are moist and rainy, and north winds are dry; the former come from hotter latitudes, where they have taken up more vapour than they can sustain in colder places; the latter generally have much less than they can sustain. This rule, however, is greatly modified by the position we hold in reference to the great seas; thus in Europe, south-west winds, which have come over the Atlantic, are the most damp; south-east winds, which arrive a good way over land, are less charged with moisture.

108. The daily and yearly courses of the sun cause daily and yearly fluctuations of the temperature, moisture, and pressure of the atmosphere; or in the thermometer, hygrometer, and barometer, which measure these fluctuations:—

109. With regard to *temperature*, the *daily* fluctuation follows the career of the sun. It is lowest, or at a *minimum*, a little before sunrise, and it increases gradually from this time till two o'clock in the afternoon, when it is generally at its highest or a *maximum*. Although the sun is most powerful at noon, yet his effect in heating the earth does not attain its highest amount till about two hours after. From this hour the cooling commences, and goes on during the decline of the day, and through the night, till about half an hour before the reappearance of the sun in the morning. From observations made at Leith, it was found that the average hour of least temperature for the whole year was five in the morning, and the average hour of greatest temperature two hours and forty minutes in the afternoon. From the same observations it appeared that the hours when the temperature was the

same as the average temperature of the day, were 9 hours 13 minutes morning, and 8 hours 27 minutes evening, taking the mean of the whole year. These hours, which represent the average of the day, are not the same in all places; they vary with the latitude and the elevation; but the interval between them appears to be pretty constant, and amounts to about 11 hours 12 minutes.

110. In the *annual* fluctuations of temperature, we find a similar course of rise and fall: there is an increase to a maximum in summer, and a decrease towards a minimum in winter. The intensity of the sun's rays is greatest in June, but the greatest heat occurs in July, or about a month after the longest day. In Paris, the highest temperature has been observed to happen on the 15th of July, and the least on the 14th of January. The days whose temperature is the mean or average of the whole year are about the 22d of April and the 20th of October. It is true alike of the daily and the yearly variations, that the change of temperature is more rapid in the increase than in the decline. In Europe, a distinct check to the rise of the temperature occurs almost invariably in the middle of February, caused by the cold east winds of spring.

111. The fluctuations of *vapour* follow the changes of temperature. As the temperature rises, evaporation increases, and the amount held in the air becomes greater. On the other hand, the diminution of the temperature leads to precipitations, and lessens the amount of the steam atmosphere. As the sun ascends in the heavens each day, the evaporation is promoted, and the absolute quantity in the air is increased; but this additional portion being very small in proportion to the whole increase of temperature, the actual dryness of the air is also increased until the maximum of heat has been attained. With the decline of the day the dryness diminishes, without a diminution of the actual amount of vapour, until the air cools down to the dew-point, when precipitation must begin. The dew-point temperature is every night sunk at least as low as the least temperature of the night. Thus if the dew-point in the afternoon is at 30°, and the air at 40°, there will be no precipitation of dew, mist, or rain, while the air is cooling down from 40° to 30°; but should the cooling not stop at 30°, but go on to 25°, all the vapour that cannot be sustained at 25° must be thrown out, and 25° will be the temperature of the dew-point; and it will remain so till the sun rise, and fresh evaporation commence. It is found that the evaporation of a single day can raise the dew-point temperature only a very short way, so that it is nearly the same

at noon as it was the previous night; and as its temperature at night was determined by the lowest temperature of the air during the night, we have the means of ascertaining the dew-point for any day with considerable exactness, by finding the least temperature of the night previous. Thus if the lowest temperature of the night be 36°, the dew-point temperature for the whole of the next day will be about 36°, or perhaps a little above it.

112. The dryness of the air at the height of the day, and the average dryness of the whole day, may be determined on the same principle. The dryness of a day depends on the difference between the highest temperature of the day, and the least temperature of the night before; thus if the maximum day temperature were 60°, and the minimum of the previous night 40°, the dryness would be very considerable. But if the least temperature of a given night, and the greatest temperature of the next day, are very nearly equal, the air will be almost saturated with moisture the whole day. Thus dryness depends on cold nights preceding warm days; a warm night, or a series of warm nights, are almost sure to be followed by sultry days. Hence one of the most important of thermometrical observations is the *range* of temperature for the day, or the greatest and least temperatures of each day. Over the sea, on the sea-coasts, and on islands, there is very limited range of temperature, and a great amount of moistness of the air. It is not uncommon to find warm and sultry nights followed by heavy rains; but an extremely cold night can hardly by any possibility be followed by a rainy day. On the contrary, a very low thermometer at night betokens that next day will be dry and clear.

113. This rule, which connects the lowest temperature at night with the dew-point of the following day, may be violated by such accidental causes as the flowing in of warm, cold, or moist air, to change the character of the place. Thus suppose the dew-point reduced to 30° by the cooling of the night, and that in the morning a south-west wind arose, warm, and loaded with vapour, the effect of this importation of moisture from other regions would be to raise the dew-point all of a sudden up to the degree of the new current. On the other hand, a warm sultry night, in which the dew-point stands at 40° through the whole night, may be followed by a day when a cold dry wind prevails, which will lower the temperature of the moist air, and precipitate a large share of its moisture as mist, fog, or rain, and depress the dew-point accordingly. It may also happen that the cold of the

night may not descend so low as the dew-point, so that the least temperature will not be the same as the dew-point temperature for the next day, but somewhat higher. In spite, however, of such casualties as these, the rule is generally true, and is very important in its applications, to inform us of the state of the air in respect of moisture, by means of the thermometer alone. If we take the lowest temperature of a night, and the average or mean temperature of the next day, the difference of the vapour sustainable at each will give the average dryness of that day. Thus if the minimum at night were 35°, and the average of the day 42°, then

Vapour at 42°, ...	·283 inch.
... 35°, ...	·222 ...
Dryness, or capacity for additional vapour,	·061 inch.

Again, if the average temperature were 60°, and the lowest temperature 45°:—

Vapour at 60°, ...	·523 inch.
... 45°, ...	·315 ...
Dryness, ...	·208 inch.

114. In this last case the dryness is more than three times as great as in the other. And to prevent mistakes, it must be remembered that a difference of a certain number of degrees will cause a much greater dryness at a high temperature than at a low. Thus let us compare the extreme dryness of a winter and a summer day, on the supposition that in both cases the greatest range of the thermometer is 20°. Let the lowest temperature of the summer day be 50°, for example, and the highest 70°:—

Vapour that could be contained at 70°, .	·727 inch.
... ... 50°, .	·373 ...
Difference, or extreme dryness of the day,	·354 inch.

Again, let the lowest temperature of the winter day be 30°, and the highest 50°:—

Vapour that could be sustained at 50°, .	·373 inch.
... ... 30°, .	·192 ...
Difference, or extreme dryness of the day,	·181 inch.

Thus the dryness of the winter day is less than half that of the summer day, although they have both the same range of 20°. And if we consider that a range of 20° is very often attained in summer, and very rare in winter, in a country like ours, we can judge what an immense difference there must be between the two seasons in point of dryness. We therefore see that both in the daily and the yearly fluctuations, the vapour contained in the air, and the dryness or the additional quantity that could be contained, are directly dependent on the course of the temperature. As a general rule, the air is drier at the increase than at the fall of the day and of the year. The morning is drier than the evening, and the spring is drier than the autumn. In the one case the temperature is increasing, and leaving the dew-point, as it were, at a greater and greater distance behind it; in the other case, the temperature is falling, and coming gradually nearer to the point where precipitation must begin.

115. With regard to the fluctuations of *atmospheric pressure*, as shown by the rise and fall of the barometer, it is found that between the tropics these fluctuations are very small, not extending to much above a quarter of an inch; but beyond the tropics they are very great, and the barometer has a range of three inches. The abundant aqueous precipitations which take place on each side of the tropics are the cause of these extensive fluctuations. On the equator itself, and in the region of the trade-winds, there is a powerful and constant evaporation, but comparatively little precipitation. All accidental variations are greatest in the latitudes beyond the tropics.

116. The barometer has in all places a regular daily fluctuation. From mid-day it falls until between three and five in the afternoon; it then rises again till between nine and eleven in the evening. It falls again to a second minimum about four in the morning, and rises to a second maximum about ten in the morning. The hours are not exactly the same for all countries, and the extent of variation is also different in different places, but the rise and fall twice in the twenty-four hours is a universal occurrence. In the tropics, the maxima or greatest heights occur at nine morning and evening, and the minima between three and four morning and afternoon. Near Edinburgh, the hours are about ten and four. The extent of the fluctuation diminishes as the latitude increases, according to a regular law. At Edinburgh, it is, on the average of the whole year, about $\frac{1}{100}$th of an inch; near the equator it is about ten times as great. The amount is also greater in summer than in winter. In the tropics, the variation is smaller on the open sea than in the interior of continents, showing that it is greatest where the extremes of temperature in the day and night are greatest. The hours of maxima are farther from noon in spring and summer than in

autumn and winter; that is, if they are at ten in winter, the morning hour will be before ten, and the evening after ten in summer. There can be no doubt that these variations are connected with the daily variations of temperature and vapour arising from the course of the sun, but the exact way in which they are produced is not very clearly understood. The afternoon minimum of the barometer corresponds nearly to the maximum of heat and of vapour, and the increase of these two quantities causes a lengthening of the column of the air, and a partial overflow upon the regions that are less charged. The morning minimum is near the minimum of the air temperature, and therefore happens at the time when vapour is apt to be precipitated by the cold of the night; and the precipitation of vapour of itself has an influence in making the barometer fall, by throwing out its latent heat into the atmosphere, and in this way lengthening the column, and causing it to overflow.

117. Beyond the latitude of 64°·8 the oscillation changes its character: the hours of greatest height are the same as the hours of least height in the other latitudes; or the maxima are about four morning and evening, and the minima about nine or ten, showing that a compensation to a certain extent is made in the polar regions for the fluctuations in the temperate and tropical regions.

118. As we ascend in the air above the sea-level, or descend into the earth beneath it, we find a change of temperature. In ascending, the air becomes colder, at the rate of one degree of the thermometer to about 352 feet of ascent; the decrease of temperature being somewhat greater in high than in low latitudes, and not so much at great heights as near the earth's surface. The causes of this are the distance from the solid earth, on whose surface the warmth chiefly resides, and the diminution of the thickness of the atmospheric covering, which serves to retain heat upon bodies, by resisting the radiation from their surfaces. It is therefore always colder at mountain tops than on the low grounds. At a certain height over every place, water will freeze, and if a mountain rise to this height, it will be covered with snow; all clouds at such a height must consist, not of water, but of ice-particles. Thus if the temperature were 52° at the sea-level, at the height of 6540 feet it would be 32°, or freezing. At 35° on the plains, a hill 1200 feet high would have its summit covered with snow. Mountains whose height is so great, that the temperature on their tops cannot rise above 32° under the greatest summer heat, are covered with eternal snows; and of course in winter the snow descends much farther down

their sides. The height over any place where water must be frozen at all seasons is called the *snow-line*, the altitude of which is greatest at the equator, and diminishes as the latitude increases. At a certain high polar latitude it reaches the mean sea-level; that is to say, the ground at that level is eternally clad with snow.*

119. Under circumstances that favour the radiation of heat from the earth, the temperature of the air increases with the height for a short way, owing to the earth cooling the faster of the two. Thus it sometimes happens, immediately after sunset, that the air is warmer as we ascend, up to the height of about 100 or 110 feet, but never more. This is of course a very trifling exception to the great principle stated in the preceding paragraph.

120. When we descend into the depths of the earth, by digging wells, or mines, we find also a variation of the temperature. The influence of the sun is extinct about 100 feet below the surface; the difference between the day and night temperatures disappears at the depth of four feet; and the influence of summer and winter vanishes at about sixty or seventy feet, at which depth the temperature always stands about the average temperature of the climate; hence the temperature of spring water proceeding from this stratum may be taken as the mean temperature of the place. At depths less than sixty feet, the ground is somewhat warmer in winter than in summer, but at greater depths the temperature is always the same. This depth, where the influence of season ceases to be felt, is called the *invariable stratum*. Beneath it the temperature increases gradually as we descend, showing that the earth has a warmth of its own independent of the sun, or what is called its *central heat*.

121. According to some observations upon the increase of the central heat, it appears that for every 59 feet of descent, the temperature rises one degree (others make the increase more rapid); so that if the temperature of the invariable stratum, or mean temperature of the place, were 52°, a depth of 10,000

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* The *snow-line* is found at various heights, according to latitude, proximity to the sea, and other causes, which affect the general climate of the region. In the Himalayah and Andes, it is found at an elevation of about 17,000 feet; in the Swiss Alps, at 8500 feet; and in the Scandinavian range, at 3500 feet. Generally, in those countries which are near the equator, the snow-line is found about 16,000 feet, or three miles above the sea-level: about the 45th parallel in either hemisphere, it occurs at an elevation of 9000 feet; under 60° of latitude, at 5000 feet or thereby; under 70° latitude, at 1000 feet; and under 80°, the snow-line comes down to the mean sea-level; for countries which are 10° distant from the poles are covered with snow all the year round.

feet would give the temperature of boiling water, which would show how far down the water lies which comes up in boiling springs; at 60,000 feet, lead would be melted; and at 20 miles, cast-iron would be liquid. We have no means of knowing if the heat increases steadily in this manner to the centre; but it is highly improbable that it should do so. We see, however, that volcanoes can be fed with burning matter, if their craters are connected with a stratum sufficiently deep to have the required temperature.

LAWS OF WEATHER.

Characteristics of Winds—Whirlwinds—Hurricanes—Rains—Storms.

122. By the laws of weather is understood the fixed relations that have been discovered between the various circumstances of temperature, vapour, pressure, wind, rain, &c.; or all those cases where some peculiar kind or state of one of these things has been always observed to accompany a particular state of some other. Where such laws, rules, or fixed relations have been ascertained, we can infer one of the things from the presence of its invariable accompaniment, and can thereby often predict heat or cold, storm or calm, rain or dryness, before they actually happen.

123. We shall consider, first, the various kinds of *winds*, and their laws of connection with temperature, vapour, and pressure. We have already seen the nature of the great equatorial and polar currents, which take the lead of all other winds. The lower current towards the equator, by coming from a colder to a warmer region, is apt to be comparatively cool and dry; while the upper current must be very moist and warm. This great characteristic difference between these two currents is found all over the earth. It is a general rule in our hemisphere, that north-east winds are cold and dry, and south-west winds warm and moist. There are exceptions to this principle produced by the irregularities of land and sea climates, but it is true in the great majority of instances.

124. The trade-winds have their direction and character somewhat changed near the western coasts of great continents, by the action of the sea and land-breezes which are there produced. They are rendered drier by blowing over continents than when passing over seas. On the great ocean, their amount of moisture must always be great, and it has been noted by seamen that a slight diminution of this gives them a *fresher* character to the feeling.

125. The desert winds, as already noticed, are excessively

dry. The *harmattan* may be supposed to have, with a temperature of 90°, the dew-point as low as 32°, which would leave a dryness or vacancy amounting at about an inch of the barometer. The *sirocco* of Italy is a dry desert wind. The fine sand or dust suspended in these winds is likewise very injurious to the human system.

126. The upper west winds begin to be felt on the earth at about 30° of latitude, and they give a westerly character to the breezes between 30° and 40°, and in a less degree to the breezes of still higher latitudes. But their action is most furious and stormy immediately beyond the border of the trades, as at Madeira in the northern hemisphere, and at the Cape of Good Hope in the southern. Direct proofs have been furnished of the westerly character of the upper currents in places where the easterly trades prevail below. At the summit of the Peak of Teneriffe, almost all travellers have found west winds, while the regular trade (which is easterly) was prevailing at the level of the sea. The ashes of the volcano of St Vincent on one occasion were carried from west to east, to the astonishment of the inhabitants of Barbadoes, who were experiencing at the time the easterly wind. The regular character of the westerly winds beyond the trades is nearly as much depended on by navigators as the steadiness of the trades themselves. But their regularity is not so great in the northern as in the southern hemisphere.

127. The meeting of the upper and under currents in the course of the descent of the upper to the earth is often productive of huge eddies, whirlpools, or whirlwinds, which move to great distances, and sometimes reach the earth, and play frightful havoc. The whirl or rotation which they have acquired causes a far higher rapidity of motion than ever occurs in a merely progressive wind. The phenomenon is similar to that which happens in streams of water meeting another; eddies are produced, and sometimes move along the stream for a considerable way. Violent winds or hurricanes also arise very frequently in mountain regions, where the currents of air are obstructed, and made to meet one another in defiles and corners. Just as water dashing through rocks acquires an irregular violence, so the interruptions and meetings of winds in the mountains generates hurricanes of tremendous power. In the Swiss Alps these are frequently experienced, as well as in the Andes in America. The irregular actions of mountains and sea and land often cause more than two different currents to exist in the air at the same time, at different heights, which may be determined by the motions of the clouds.

128. Besides the peculiarities of temperature and dryness, the two great primary currents of the globe are often distinguished by different *mechanical* characters, or differences in the manner of their motion. The lower or north-east current originates below, and sweeps close over the land the whole of its course; it is a *raking* wind.* When, as in the case of our north-east winds, it is brought over a wide extent of cold and marshy ground, it is apt to bring with it unhealthy effluvia and damp from the soil, which render it disagreeable and noxious. The north-east winds of this country originate in the north of Europe, and become tainted by the low swamps of the Russian continent. These winds have also a very slow and steady current; their motion is often so slight and invariable, that they are scarcely felt; and their action on the human system is insidious and unsuspected. The west winds, on the contrary, descend from the higher regions, and have far less contact with the ground; hence they are much purer and more wholesome. They are, besides, fitful and gusty, from tumbling through other air, especially at the places where they first descend. We may often observe, in a day when a westerly wind prevails, that the streaming smoke of a steamer is every now and then violently blown downwards, as if by a gust from above. The days when the wind seems to change its direction every few minutes, rendering it impossible to know which way to hold an umbrella, are distinguished by westerly winds, which are fed by the descent of the great upper current.

129. The conflict of the north-east and the south-west cur-

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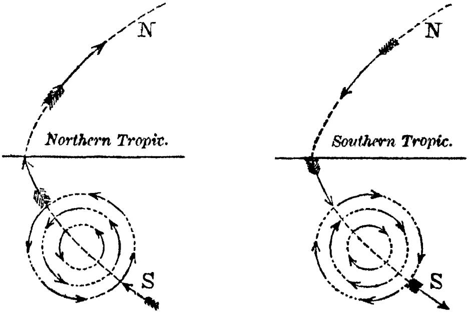
* Every gradation exists in the speed of winds, from the gentlest zephyr to the most violent hurricane. They have been classed by Smeaton, according to their rapidity and force, as follows:—

Velocity. Miles per Hour.	Force on 1 square foot, in lbs. Avoirdupois.	Appellation.
1	·005	Hardly perceptible.
4	·079	Gentle breeze.
5	·123	
10	·492	Pleasant brisk gale.
15	1·107	
20	1·968	Very brisk.
25	3·075	
30	4·429	High wind.
35	6·027	
40	7·873	Very high.
50	12·300	Storm.
60	17·715	Great Storm.
80	31·490	Hurricane.
100	49·200	Violent hurricane.

rents, when they are both at the level of the ground, will produce a great variety of intermediate winds. A German philosopher, M. Dove, has attempted to show that the winds succeed one another more frequently in one course than in the opposite. In the northern hemisphere, the changes are most usually from south, by west, north, east, to south again, or what is called a right-handed direction; while in the other hemisphere they most frequently move from south, through east, north, west, to south, or by a left-handed direction. Hurricanes in the two hemispheres are said to sweep in opposite directions, and to rotate as indicated by the concentric circles and arrows in the accompanying diagram:—



130. The following paragraph from Muller's Physics expresses M. Dove's views:—"When the *south-west* wind, constantly increasing in force, at length predominates, it raises the temperature above the freezing-point, and the snow is consequently converted into rain, whilst the barometer falls to the lowest mark. The wind then veers round to the *west*, and the dense flakes of snow indicate the accession of a colder wind, no less than the rapid rise of the barometer, the motion of the weathercock, and the thermometer. A *north* wind clears the heavens, and a *north-east* wind effects a maximum of cold and of the barometer. This, however, is gradually lowered, and the occurrence of fine cirri indicate, by the direction from which they have come, the advent of a more southern wind, which is soon felt by the barometer, although the weathercock may not have experienced any change, and may still be pointing due east. The *southern* wind, however, continues to drive the eastern current downward; and on a decided falling of the mercury, the weathercock points *south-east*, when the heavens again become gradually overcast; and with the increase of

heat, the snow which had fallen with a *south-east* and a *south* wind is again converted into rain by the *south-west* wind. The same then begins again, the change from the east to the west course being generally characterised by the occurrence of a short interval of fine weather."

131. With regard to the *temperature* of winds, it is found that, on the whole, the north-north-east is the coldest and the south-south-west the hottest. In summer, the north-north-west is sometimes the coldest, and the south-east the hottest. The rule, however, varies in different places. In London, the north wind appears to be the coldest.

132. The winds between north and east have generally the smallest amount of *vapour.* At the same time, from their being the coldest, their actual dryness, or the difference between their temperature and the dew-point, is often less than in other winds. The south winds have both the greatest amount of vapour and the greatest vacancy or dryness. The cirro-cumuli clouds are indications of the south wind, and foretel heat; as they show that, although the wind be warm, it does not bring so much vapour as to cloud the heavens, and lead to a precipitation. The cirri, or feather-clouds, in summer, announce rain, and in winter frost or thaw. They are generally carried by south or south-west winds; and though these may be only in the upper regions at first, they soon come to be felt at the surface.

133. The *pressure* of the air, or the height of the barometer, varies during the different winds. The barometer generally falls during east, south-east, and south winds; passes from falling to rising during south-west; rises with west, north-west, and north winds; and has its greatest rise with north-east winds. The rise of the barometer with a north-east wind is very commonly remarked. The mercurial column is usually at its lowest between south and south-west.

134. A connection has been discovered between the height of the barometer and the force of the wind in the course of the daily barometric fluctuation. The mean velocity of the wind is found to be greatest at the period of the afternoon minimum of pressure.

135. The laws that relate the amount of *vapour* to *season temperature* and *pressure* are also of great importance, as well as the relations of the wind to these. The daily maximum both of vapour and of dryness, is in the afternoon between four and five, and the minimum of both takes place early in the morning. With respect to the year, the maxima and minima are, the one in July, the other in January. Near the sea-level the quantity of vapour in the different seasons fol-

lows the course of the mean temperature. It often happens that, during the daytime, clouds are abundantly formed in the sky, and disappear after sunset. This is owing to the copious supply of evaporation during the heat of the day, and the cessation of it at night; in these cases a clear morning often passes into a cloudy day, owing to the influence of the sun in recommencing the evaporation that had been previously suspended.

136. It is a general law, or invariable connection, between the amount of vapour and the pressure of the atmosphere or the height of the barometer, that they change in opposite directions. In summer, when the quantity of vapour is greatest, the pressure of the air is least; and in the winter time, the vapour being least, the weight of the air is greatest. Even in the daily fluctuations of these two quantities this opposition is perceivable.

137. The fall of *rain* will depend upon the quantity of moisture usually present in the atmosphere, upon the nearness of the air to saturation, or of the dew-point to the air temperature, and on the fluctuations or sudden falls of temperature that take place. In hot countries, where the total vapour of the air is greatest, the amount of rain discharged in the course of a year, and in single showers, is greatest. On the sea-coasts, and in places visited by moist winds, in which the approach to saturation is highest, the falls of rain will be most frequent, and there will be a greater degree of cloudiness prevalent in the sky. In the interior of continents, where the dryness is great, or the dew-point generally much lower than the temperature, rain will be less frequent, and the sky will be more transparent. In England and the west of France there are, on an average, 152 rainy days in the year, in the interior of France 147, in the plains of Germany 141, and in the interior of Siberia only 60. In many parts of Africa rain never falls; in Upper Egypt it is very rarely known. On the west coast of Britain it rains much more frequently than on the east; the reason being, that the westerly winds (from the Atlantic) are moist winds, and give forth the greatest quantity of moisture on the land upon which they first strike. When the air is subject to sudden falls of temperature, it must also give forth a great quantity of rain.

138. A soil moist and hot, such as the coasts of England, which are washed by a warm sea, will, when the air is cold, as at night and in winter, yield *fogs*. Swampy and undrained land likewise must of necessity cause fogs.

139. When the visible vapour from a hot spring, a boiling caldron, or a steam-engine, extends in a long train, it is a

sign that the air is nearly saturated with moisture, and that rain may be expected. If the appearance occurs about two or three o'clock in the afternoon, it may be reckoned as certain that there will be rain, mists, or dews at nightfall.

140. In extreme frosts there can never be great falls of snow, the whole of the moisture contained in the air being too small to afford a copious precipitation.

141. In *predicting* weather by consulting instruments, it would be necessary to use the hygrometer along with the barometer and the thermometer. There are many exceptions to the common expectation, that a high barometer indicates fine weather, and a low barometer the contrary. But even the barometer alone would be more certain if the following points were attended to—namely, in the *first* place, the actual height of the mercury; *secondly*, whether it is rising or falling; *thirdly*, the rate of rise and fall; and *fourthly*, whether the rise or fall has been of long duration. A slow rise, continued for some days, gives promise of settled weather; a steady and long-continued fall indicates that a tract of unsettled and stormy weather may be expected. There are also certain hours of the day which ought to be preferred for making the observations. For three observations daily, the proper times are—nine A.M. (a maximum height), twelve noon (a mean height), and three P.M. (a minimum height); when convenient, a fourth should be added—namely, three A.M. For two observations daily, nine o'clock morning and evening are the best hours; for one daily, noon is preferable. These are the hours best suited for taking observations which are to be kept on record, and also for consulting the instrument to prognosticate the weather. If the column rise between nine A.M. and three P.M., it indicates fine weather; if it fall from three P.M. to nine P.M., rain may be expected. These rises and falls are contrary to its regular daily course, and therefore indicate considerable changes in the pressure of the air.

142. A sudden and great fall of the barometer is the sure forerunner of a violent storm. It shows that a great displacement or vacancy has occurred in the air over the place, and that a great inward rush will occur to make it good. A sudden rise would indicate an accumulation of air, which would cause an outflow in all directions, and would be also felt as a storm somewhere. A slow rise or fall shows that the influence comes from a great distance, or is owing to a permanent cause; hence, whatever the consequence may be, it will probably last for some time. A high barometer is a security against vehement influxes of air on any side,

and therefore against the carrying in of moisture; hence it prognosticates dry and clear weather.

143. The hygrometer is very valuable in predicting weather; for as the quantity of vapour in the air increases or declines, so does the probability of the occurrence of rain. A sudden change in the dew-point is generally accompanied by a change of wind, and precedes it by a short interval, although the change of wind is commonly the cause, and the hygrometric change the effect.

144. The hours already stated for the observation of the barometer are also well adapted for the hygrometer, with the view either of keeping a register, or of ascertaining the course of the weather. The average pressure of the vapour for the day should be calculated by taking a mean between the dew-point at three P.M. and the lowest temperature of the sheltered thermometer at night.

145. By examining the barometer along with the hygrometer, the prediction of weather is made much more certain. A fall of the barometer, accompanied with a rise in the dew-point, is an infallible indication that the entire mass of the air is becoming imbued with moisture; and a copious fall of rain may be looked for. If the fall of the barometer take place when the dew-point is low, we may conclude that the expansion that has occasioned the fall has taken place at a distant point, and wind without rain will be the result. When the temperature of the air sinks to the dew-point, with a high barometer, the effect is probably transitory, and produced by a local depression of temperature.

CLIMATES.

Isothermal Lines—Zones of Distinct Vegetation—Insular and Continental Climatology—Climate of London.

146. The climate of a place depends on its distance from the equator, its height above the sea-level, its position in reference to oceans, seas, and continents, the form of its surface, and the character of its soil. The points to be stated in reference to climate are, the mean temperature, the extreme winter and summer temperatures, the range of temperature daily, and from day to day, the humidity, the total fall of rain, the frequency of the falls, the relation of the amount fallen to the ordinary amount of vapour in the air, the prevailing winds, and the degree of variability of the weather. In general, the southern hemisphere of the globe is colder than the northern.

147. Humboldt divided each of the two hemispheres into seven belts or zones of climate, by supposing lines to be drawn round and round the globe, somewhat like parallels of latitude, each line running through all places whose *mean temperature* is the same. These are called *isothermal lines;* and as vegetation depends on warmth, they serve to distinguish the zones of distinct vegetation.*

148. Next the equator is the *equatorial* zone, or the *spice* climate, bounded by the line passing through places of 78° of mean temperature, which line lies nearly at 20° of latitude. The finest spices and the hardest woods thrive in this region. The second zone is the *tropical* climate, and is bounded by the line of 68°, and includes the climate of the sugar-cane and coffee-tree. In North America it is 31° from the equator; in Europe, the Mediterranean, Asia Minor, and Syria, it extends to 37° latitude; in Persia to 31°. Here all the species of the palm-tree are in great perfection; the orange, lemon, and citron are of the most delicious flavour; and Indian corn, rice, cotton, tobacco, indigo, dyewoods, and drugs, are also among the productions. The third or *warm* climate extends to the line of 59°, the boundary of the olive and fig. In America it extends to latitude 36°; in Europe to latitude 44°; in the west of Asia it extends to 40°; and in the central high regions to 35°. This zone yields the olive, fig, almonds, peaches, apricots, the mulberry for feeding the silkworm, the vine, yielding the choicest wines, the cork-tree, drugs, barilla, dried fruits, &c. The fourth or *temperate* climate coincides with the line of 50°, mean temperature, and is the limit of the wine-grape. In the middle of Europe it extends to latitude 50°, on the coast to 52°; in England and Ireland to 53°; in America, on the east coast, to 43°, and on the western coast to about 50°; and in Asia it is as low as 40° latitude. It is the climate of grain, of the oak, beech, maple, and other valuable timbers; also of plums, cherries, apples, and pears. The fifth or *cold* climate terminates at the line of 41° of temperature, which is the northern boundary of the oak and of wheat: it yields the pine and fir, oats, barley, rye, apples, pears, nuts, gooseberries, and strawberries. The sixth or *frozen* climate is bounded by the line of 32°, or freezing: it extends in Lap-

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* Places which have the same mean annual temperature vary considerably in their mean summer and winter temperature; hence *isochimenal* lines, or lines of equal winter temperature, and *isotheral* lines, or those which show equal summer over points upon different isothermal curves. Another set of lines or curves, called *isogeothermal*, connect those places where the temperature of the soil is equal at or beneath the surface.

land to 66° latitude; and to Table Bay, Labrador, at 54°. It contains little vegetation; its chief productions are animal products, such as whalebone, train-oil, and furs. Beyond this is the seventh or *polar* climate, which extends to the region of perpetual snows, where all vegetation ends: it yields only a few stunted shrubs, lichens, and mosses.

149. In ascending a mountain, we find a gradual diminution of temperature, analogous to the transition from the equator to the poles; and the same succession in the classes of vegetable life. On the sides of Teneriffe, Humboldt observed the vegetation of nearly all the climates of the world. In temperate latitudes, though the variety of vegetation be less, similar phenomena present themselves. "We may begin the ascent of the Alps, for instance, in the midst of warm vineyards, and pass through a succession of oaks, sweet chestnuts, and beeches, till we gain the elevation of the more hardy pines and stunted birches, and tread on pastures fringed by borders of perpetual snow. At the elevation of 1950 feet the vine disappears; and at 1000 feet higher the sweet chestnuts cease to thrive; 1000 feet farther, and the oak is unable to maintain itself; the birch ceases to grow at an elevation of 4680, and the spruce fir at the height of 5900 feet, beyond which no tree appears. The rhododendron ferrugineum then covers immense tracts to the height of 7800 feet, and the herbaceous willow creeps 200 or 300 feet higher, accompanied by a few saxifrages, gentians, and grasses, while lichens and mosses struggle up to the imperishable barrier of eternal snow."

150. But the mean temperature is not the only circumstance which determines the vegetation of a place. The boundary of some plants depends on the lowest temperature of winter; and the advantageous cultivation of most plants is ruled by the greatest summer heat, as in the case of the vine, the olive, and maize or Indian corn. Barley is said to ripen wherever the mean temperature of 90 consecutive days rises to 48°. Hence, besides the lines of mean temperature drawn round the globe, it has been proposed to draw two other sets of lines,—one through all places whose summer heat is equal, and the other through places of equal winter cold. As a general rule, annual vegetables are insensible to the cold of winter, and depend on the summer temperature.

151. Mean temperatures must be determined by the average of a great many observations of the thermometer, or from the temperature of springs proceeding from a certain depth, on the principles already explained in regard to the cessation of daily and yearly fluctuations at given depths. It is highly

improbable, and in opposition to all evidence, that the mean temperature of any place on the globe has been changed within the periods known to history.

152. Between the tropics the year is divided into the wet and the dry seasons. The wet or rainy season is the summer, or the time of the sun's most direct action; in *north* latitudes it extends from April to October. In the dry season, in tropical America, entire months pass away without a cloud being seen in the heavens; the plains become desert, the grass is dried up, the earth cracks, the alligators and serpents lie buried in the mud. At the end of February, the blue of the sky becomes less intense, the humidity increases, the starry light is fainter, the breeze is weaker, and is sometimes interrupted by dead calms. At the end of March, gleams of lightning appear in the south, and the direction of the wind passes to west and south-west, away from the regular course of the trades. This is the approach of the rainy season, which commences at the end of April The sky then becomes gray, the heat increases, and dense vapours are poured over the heavens; frequent thunder-storms burst forth, and are followed by the rain torrents. In the west coast of India, the dry season is during the north-east monsoon; and the rainy season is the other half of the year, or in the summer months, the rains being most abundant in July.

153. The division of the year into four seasons is known only in the temperate zones, or between 40° and 60° of latitude. In these climates the rains and winds are variable and uncertain as compared with the tropics. As we approach the polar seas, the irregularities of the wind increase; storms and calms alternate without warning; and ships within the same visible circle may suffer every variety of wind and weather.

154. Without the tropics, a fall of the barometer almost always precedes a period of rain, and indicates an acceleration or change of the aërial currents. The immediate cause of a fall in the mercury is an accumulation of aqueous vapour.

155. The western coasts of continents beyond the tropics have a much higher temperature than the eastern coasts, arising from the heat evolved in the condensation of vapour from the prevailing westerly winds.

156. Next to the distinction of climates into hot and cold, is the difference between *insular* and *continental* situations. Insular climates are kept temperate by the sea; they do not experience the extremes of heat and cold that are felt in the interior of continents. Thus if we compare Nova Zembla with Fort Franklin, which have nearly the same mean tem-

perature, we shall find in the extremes of each the indication of its position:—

	Nova Zembla.	Fort Franklin.
Mean temperature, . .	16°·	17°·6
Mean of three summer months, .	36 ·5	50 ·4
... ... winter	—3 ·	—17 ·8
Extreme heat, . . .	49 ·	80 ·
... cold, . . .	—53	—58
Range of heat and cold, . .	102	138

157. Both the vegetation and the feelings of human beings will be very different in these climates. The high summer heat of the one will favour the growth of many plants, and give a tone of warmth and cheerfulness; the miserable cold mediocrity and monotony of the other will be barren and disheartening.

158. The British islands are situated so as to experience almost all the circumstances which can render a climate irregular. Standing nearly in the centre of the temperate zone, where the range of temperature is very great, they are subject on one side to the impressions made on the atmosphere by the greatest continent of the world, and on the other side to the influences of the Atlantic Ocean. They are also within reach of the great fields of polar ice, which counteract the force of the summer sun, and present an additional evaporating surface to the air.

159. On the average of ten years, the westerly winds are to the easterly, in Great Britain, as 225 to 140; and the northerly to the southerly as 192 to 173. Of east winds, the northerly exceed the southerly in the proportion of about 74 to 54; thus the south-east, which is the most irregular point of all, has but a small proportion. The south-west are to the south-east as 104 to 54. The north wind ought to prevail throughout the year, as it does to a great extent in the south of Europe, especially in summer, under the denomination of the *Etesian wind*. But the condensation of vapour to the north and north-east causes perpetual diminutions of the aërial columns, and consequently determines frequent currents from south to north.

160. Northerly winds almost invariably raise the barometer; southerly winds as constantly depress it. The southerly wind brings vapour, whose condensation leads to a fall of the mercurial column; the northerly wind prevents and reduces the accumulation of vapour, and dissipates the heat that would expand the aërial column, and lead to an overflow and diminution of pressure.

161. The most permanent rains come from the south. As

a general rule, rain must arise from one of two sources—namely, either from the vapour raised over the locality where it falls, or from the vapour brought from adjoining places. It requires some sudden cooling to convert the first kind into rain, but the other may yield a constant supply without any extraordinary cold. Moist and saturated winds passing into cold regions necessarily give out part of their vapour; hence the southerly winds in the northern hemisphere will be the most frequent sources of rain. The south-west winds from the Atlantic pour forth a vast quantity of vapour every year upon the British islands.

162. Within the boundaries of Great Britain there is a considerable variety of climate. The character of each place can be ascertained only by a long series of well-conducted instrumental observations; and few places have as yet received this degree of attention. Hitherto London has been the place most carefully observed, and the general character of its climate has been described by Howard and Daniell. In a few years it will come to be still more completely ascertained by means of the meteorological observations which have recently been commenced at the Greenwich Observatory, as well as from those at the Kew Observatory, which are in addition to the long-continued series of observations made by the Royal Society of London.

163. The mean pressure of the air at London, as deduced from twenty years' observations by Mr Howard, is 29·8655, or very nearly 29$\frac{9}{10}$ inches. The mean temperature derived from the daily extremes is 49½°. The mean dew-point is 44½°, giving a mean dryness of 5°, which for these numbers corresponds to a vacancy or dryness of ·058, or nearly $\frac{1}{17}$th of an inch. The average quantity of rain is 22·199 inches annually, and the amount of evaporation is calculated at 23·974 inches—that is, considerably greater than the entire amount received by precipitation.

164. The range of the barometer is from 30·82 inches to 28·12 inches; the maximum temperature of the air is 90°; the minimum 11°; the range of the dew-point is from 70° to 11°. The highest temperature of the sun's rays is 154°, and the lowest temperature on the surface of the earth 5°. The greatest interval between the temperature and the dew-point is 29°. The average daily course of the dew-point is as follows:—From morning to afternoon it rises 0·3 of a degree, and from afternoon to night it falls 0·9 of a degree, the minimum temperature being still lower by about 2·7 degrees. The medium dew-point temperature of 44½° is made up of the following proportions of the means from eight points of the wind:—

87 North,	40°·1	133 North-east,	40°·7
80 East,	42·3	111 South-east,	45·6
70 South,	48·7	225 South-west,	48·6
215 West,	44·8	174 North-west,	41·3

165. Of these winds, one class—namely, the north-east, east, and south-east—are land-winds, and blow over from the great continent of Europe; the other class are sea-winds, blowing from the great surrounding oceans: they are the north, north-west, west, south-west, and south. Except in April and May, the dew-point of the sea-winds is higher than the dew-point of the land-winds. The exception in these two months arises from the slowness of the great seas in attaining to their summer heat. The dew-point of the sea-winds does not descend so low in winter as that from the land-winds, and its rise is much less rapid during spring than in the case of the land-winds.

166. The meteorological elements for London are given by the late Professor Daniell as follows:—

167. In January the mean temperature is 36·1°, varying from 39·6°, the mean highest, to 32·6°, the mean lowest; the greatest extremes are 52° and 11°. The mean dew-point is 34·3°, and the mean dryness 1·8°, which at this temperature is ·015 of an inch of the barometer. The average greatest daily dryness is 3·5°. The height of the barometer is 29·921, and its mean range 1·6 inches. The quantity of rain is 1·483 inches, and of evaporation 0·413 inch.

168. In February the mean temperature is 38°, the average maximum 42·4°, and the minimum 33·7°; the extreme range is from 53° to 21°. The dew-point is 34·9°; hence the mean dryness is 3·1°—a considerable advance on January. The average greatest dryness is 6·1°. Barometer 30·067 inches, and its range 1·36 in. The fall of rain is at its minimum, being 0·746 in.; evaporation 0·733 inch.

169. In March the mean temperature advances to 43·9°, and the dew-point to 39°, making the dryness 4·9°. The average greatest heat of the day is 50·1°, the minimum 37°; the whole range of temperature is from 66° to 24°. The average greatest dryness is 9·6°. Barometer 29·843, and its range 1·26 inches. Rain 1·44, and evaporation 1·488 inches.

170. In April the mean temperature rises 6 degrees, or is 49·9°, and the dew-point is 43·0°, making the dryness 6·4°. The mean maximum dryness is 12·8°. The temperature of the air ranges from 74° to 29°. The mean height of the barometer is 29·881 inches; its average range 1·11 in. The quantity of rain is 1·786 in., and of evaporation 2·290 in.

171. In May the temperature continues to outstrip the

advance of the vapour, and the atmosphere attains nearly its greatest dryness. The mean temperature is 54°, the mean dew-point 46·1°. The mean of the maximum temperatures is 62·9°, of the minimum 45·1°; the greatest range of the thermometer is from 70° to 33°. The barometer is 29·898, its range 1·09 in. Rain 1·853, and evaporation 3·286 inches.

172. In June the average heat of the air is 58·7°, the dew-point 50·7°. The maximum temperature averages 69·4°, the minimum 48·1°; the range 90° to 37°. Mean barometric pressure 30·020 inches, the mean variation 0·64. Rain 1·830, evaporation 3·760 inches.

173. In July the mean temperature of the air is 61°, of the dew-point 54·5°. The mean maximum temperature is 69·2°, the minimum 52·2°; the greatest range is from 76° to 42°. Barometer 29·874 in., range 0·79. Rain 2·516 in., the greatest monthly amount in the year; evaporation 3·293 in.

174. In August there is very little difference from July.

175. In September the reduction of temperature begins to be sensibly felt. The mean temperature is 57·8°, the mean dew-point 52·3°. The barometer is 29·931 in., and its mean range 0·88. Rain 2·193, and evaporation 2·620 inches.

176. In October the mean temperature is 48·9°, the maximum and minimum averaging 55·7° and 42·1°; the dew-point is 44·8°. Rain 2·073 inches, evaporation 1·488 in.

177. In November the air is nearly saturated with moisture; the air is 42·9°, the dew-point 40·5°. The rain is 2·400 inches, the evaporation only 0·77 inch. The mean highest temperature of the days is 47·5°, the mean lowest 38·3°; the utmost range is from 62° to 23°. Barometer 29·776 inches, and its range 0·92.

178. In December the mean temperature is about 8° lower, but the general character of the month is the same as that of November.

ELECTRICITY OF THE ATMOSPHERE.

Thunder and Lightning—Aurora Borealis.

179. Under Electricity (pars. 102-112), we have had occasion to speak of the electrical character of the atmosphere, which is at present but imperfectly understood. The charging of the atmosphere with electricity may arise from various causes, and it is known to be most intense in warm climates. The discharges of the excitement are well known under the terms *thunder* and *lightning*, and they generally accompany storms, hurricanes, and tempests; but they are rather the effects than the causes of these. The mixing and

meeting of opposite currents, which leads to wind and rain storms, also produces electric discharges when the different currents or strata happen to be in opposite states. It is supposed that the atmosphere is not of one uniform electrical state through its entire height, but changes from the one excitement to the other, so as to be a succession of positive and negative strata. Hence the descents of masses of air from one stratum to another will often cause discharges; and the natural ascent of the air by the sun's heat will charge some, and discharge others. Such a state of things makes the whole of the electrical phenomena of the air exceedingly complicated.

180. The *aurora borealis*, so startling as a meteoric phenomenon, has been supposed to be an instance of faint lightning discharged far in the upper air, where the rarity is so great that it may flash over vast spaces, as we see in an exhausted receiver. The coincidences between the aurora and distractions of the magnetic needle, render it likely, however, that it is some manifestation of magnetic, rather than of electric storms. This view is confirmed by the north and south direction of the streamers; but it must be added that the real nature of the aurora is still unknown.*

LUMINOUS METEORS.

Twilight—Rainbows—Halos—Parhelia—Coronæ, &c.

181. The various luminous appearances of the heavens, apart from the ordinary phenomena of sun, moon, and star light, are usually treated of under METEOROLOGY.

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* The following are given by Brocklesby as the principal hypotheses which have been started to account for the aurora:—Canton supposes it to be caused by the passage of electricity from *positive to negative* clouds in the upper and rarefied regions of the atmosphere. He adduces in support of this view the fact, that when the air within a long glass tube is rarefied, and electricity passed through it, the whole tube is illumined by *flashes of light*, traversing its entire length. Beccaria supposes that there is a constant circulation of the electric fluid from north to south, and that the aurora is seen whenever the electric current passes *nearer than usual* to the earth, or the state of the atmosphere is such as to render it *luminous*. Faraday has demonstrated that the electricity of the earth necessarily tends from the *equator towards the poles;* and has suggested that the aurora may possibly arise from an *upward current* in the atmosphere, flowing back from the poles towards the equator. Kaemtz conjectures that since a spark is perceived every time an electric current is broken, the northern lights may perhaps be caused by a rupture in the magnetic equilibrium of the globe. At the same time, however, he utterly disclaims the idea of accounting for all the circumstances of this wonderful phenomenon in our present imperfect state of knowledge.

182. If there were no atmosphere, the heavens would be intensely black at all times, and the heavenly bodies would be brilliant lights set in the deepest shadow. The air, however, diffuses and reflects the sun's light, so that a portion of it is received from every part of the sky, causing a general illumination of the entire vault of heaven. This reflected light ought to be always of a whitish character, like the light of the sun itself made very much fainter. But we find that the sky, when clear, has a strong blue tinge, which deepens into black as we ascend to great heights. The blueness arises from the peculiar action of the atmosphere upon light. If any white beam pass through a great thickness of air, the red will be transmitted most readily, and the blue resisted and reflected; hence the reflected rays of the sun's light have a bluish tinge instead of being pure white. The reddish character of light transmitted very obliquely through a great thickness of atmosphere, is exemplified in the ruddy illumination of the sky and the clouds at sunset.

183. *Twilight* is an effect of the refraction of light by the air, so as to make a portion reach the earth by an oblique course after the sun falls beneath the horizon. It continues till the sun has descended 18°, or for nearly two hours after sunset in this country. The illumination of the night, which continues after twilight, arises from the total reflection of some of the sun's rays in the atmosphere, which enables them to reach the earth after a still greater amount of bending.

184. On the opposite side of the sky from the setting sun, there is often a display of colour, consisting of blue and red bands; the blue being the lowest, and the red above it. The red arises from a continuation of the rays which tinge the sky in the neighbourhood of the sun in the west; the blue are the rays totally reflected within the atmosphere by passing from the denser strata to the rarer.

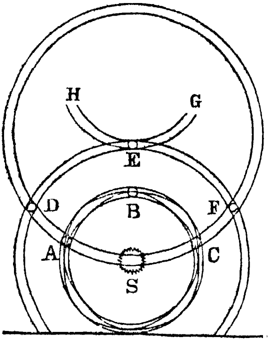
185. *The rainbow*, as described in OPTICS, is owing to a complicated reflection and decomposition of the rays of the sun in passing through drops of rain. It appears when the sun is unclouded, and rain is falling in the opposite quarter of the heavens. When a ray of light enters a drop of water, it is decomposed as it enters into the prismatic colours; the rays, on reaching the other side of the drop, are partly transmitted and partly reflected and thrown out at the same side as that at which they entered, and they emerge in the decomposed or coloured state. A great many rows of drops, all sending out coloured rays on this principle, have their rays arranged in a fixed order, and these join together, so that all of one colour appear in one band; and

the other colours unite, each in its separate band producing the rainbow as we see it. In the brightest or *primary rainbow*, the violet strip is within or lowest, the red highest. The violet rays suffer the greatest bending in the course of the two refractions, and are on that account thrown to the lowest position. When a second rainbow appears, it is above or without the first, and is called the *secondary rainbow;* it is the fainter of the two. Its rays are such as have not passed out of the drop after one reflection, but have been reflected a second time, and then transmitted. The loss incurred in these two reflections is the cause of the greater faintness.—(See Reflection in OPTICS.)

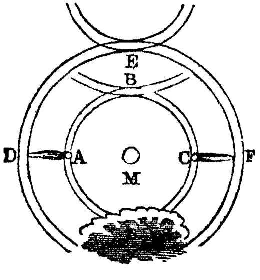
186. It is a mistake to suppose that the reflection of rays within a spherical drop of water, is on the principle of the total reflection of light on its passing from a dense medium to a rare at a particular angle. If such a reflection were to take place once within the drop, it would take place for ever; the ray could not emerge at all, unless the drops were of some other figure than spherical. If the angle were such as to cause total reflection in one case, it would still be the same when the ray reached the other side after reflection, and it must therefore be reflected again; and so on for ever. But in addition to this kind of reflection, there is a reflection which takes place, at the surfaces of all media, of a certain portion of the rays that fall upon them, as we see in water or glass; and moreover if we suppose the drops flattened by their fall instead of being round, the total reflection can then take place.

187. *Halos* are coloured rings, which surround the sun at considerable distances from his body. Two of them may be seen at once, the one about double the distance of the other; and sometimes a third, at twice the distance of the second, and about 90°, or a quarter of a circle from the sun. The smaller circles are generally coloured, the red being innermost. They are supposed to arise from the action of the icy particles in the upper air upon the rays of light. These particles naturally aggregate into needles or prisms of three or six sides, and the refraction of the light through them would account for the colours of the rings, and for the distances at which they stand from the sun. *Parhelia*, or mock-suns, and *paraselenæ*, or mock-moons, are supposed to be owing to refraction from the same icy particles. Phenomena of this kind have been arranged into four classes:—1*st*, Circles surrounding the orb which occupies their centre; 2*d*, Circles passing through the orb; 3*d*, Arcs of circles touching those of the first class; and 4*th*, Parhelia and paraselenæ found at the points where the circles cross each other.

188. The accompanying figure represents a halo around the sun, observed by Scheiner in 1630. S is the sun, A B C a circle about 45° in diameter, and D E F another circle, whose diameter is nearly 95° 20′—the sun being in their common centre. Both the circles were coloured like the primary rainbow, but the red was next the sun, the other colours succeeding in the natural order. D S F is a third whitish circle passing through the centre of the sun, and H E G a portion of a fourth circle *touching* D E F at E. At A, C, D, and F, were mock-suns; the same phenomena were observed at B and E. The mock-suns A and C were of a *purplish red* next to the sun, while D and F were *entirely white;* the former were also brilliant, continuing visible for three hours together, while the light of the latter was faint and fluctuating. The mock-suns B and E were almost the first to appear, and the last to fade, and throughout the whole phenomenon, which lasted five hours, they were perpetually changing in *magnitude* and *colour.* B was formed in a peculiar manner: the halo, A B C, was composed of several intersecting circles, and at one of these intersections the mock-sun B appeared.



189. In the annexed figure, a representation is given of a lunar halo seen by Hevelius at Dantzic, at one o'clock on the morning of the 30th March 1660. When first perceived, the moon, M, was surrounded by a complete whitish circle, A B C, 45° in diameter, while at A and C were mock-suns, displaying *various colours,* and shooting out at intervals very long streams of whitish light. At two o'clock, the larger circle, D E F, was seen reaching down to the horizon, having a diameter of 90°. The tops of both circles were *touched* by *coloured arches,* like inverted rainbows, the *red* tint being *next to the moon.* The arch B was part of a circle equal in size to D E F, while that at E was a portion of a circle of the same magnitude as A B C. Such is the general structure



of halos: the identity existing in the magnitude and arrangement of their several parts, clearly shows that they must originate in certain fixed laws; but what those laws are has not yet been fully determined.

190. The true halos are to be distinguished from the *coronæ*, or *glories*, that surround the sun or moon when a thin cloud passes over them. These depend on a different optical principle. When fine powder of any kind is interposed between the eye and a luminous object, rings of colours are formed, whose size depends on the dimensions of the powder. Visible vapour will produce this effect; and it also arises from the fine dust always held in suspension in the air of a room. Such rings can be observed round a candle flame at any time, if we stand at a proper distance from the light; and by the agitation of the dust, they may be made still more visible. By calculation, Dr Young has shown that rings 8° in diameter are produced by particles of powder, or drops whose diameter is $\frac{1}{2183}$ of an inch.

IGNEOUS METEORS.

Shooting-Stars—Fire-balls—Meteoric Stones—Aërolites.

191. *Shooting-stars* are observed during serene nights. A luminous point like a star bursts into view, shoots a certain way through space, and then disappears. Its brilliancy fades before it is extinguished. Sometimes it leaves a luminous train behind it; in other cases it gives forth sparks. These meteors have been noticed to occur in great numbers at once; and the interest of such appearances has been very much increased by the fact of their being in some measure periodical. On several years they have been found to occur in the month of November; from which circumstance they are sometimes called November meteors. They also occur with some degree of frequency in August. Shooting-stars and *Fire-balls* break out occasionally at every period of the year.

192. When a fire-ball bursts, the fragments fall to the earth, and are called *meteoric stones*, or *aërolites*, from the Greek words *aër*, atmosphere, and *lithos*, a stone. Many of these stones have been procured and examined, and found to be quite unlike any mineral of terrestrial origin. Hence the most likely theory of their derivation is, that they are fragments flying through space, under the influence of the same forces which sustain the planetary motions, and that they sometimes come within the sphere of the earth's attraction, so as to be drawn down to its surface. There is every reason to believe that the planets, satellites, and comets, are not the only bodies

which move round the sun, and lie within the solar system; they are merely the large conspicuous masses, while millions of others may exist, too small to be descried on ordinary occasions, and making themselves known only by falling upon the earth. Their illuminated appearance is supposed to be owing to the extraordinary friction that they cause in passing through the air, with such a high velocity as they must possess. To account for the periodicity of the November meteors, it is imagined that a great number of them may have a regular movement round the sun, so proportioned that they encounter the earth always at about the same place in its orbit. Some of them pass into the atmosphere, and go out again, without falling to the earth; showing that the earth can only deflect them a certain way, and is not able to draw them completely down to the surface.

193. One of the most familiar of luminous meteors is the *ignis fatuus*, or "Will o' the wisp," which appears at night on marshy grounds, places of sepulture, or wherever putrefaction and decomposition are going on. The appearance is that of a small flickering light, straggling in an irregular manner at the height of one or two feet from the ground, and sometimes standing for a few moments over a particular spot. When approached or pursued, the lights are agitated by the motion of the air, and seem to elude investigation. The cause of this species of meteor is supposed to be an evolution of phosphoretted hydrogen gas, which, properly speaking, does not burn as a flame, but is only faintly phosphorescent.